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ORIGINAL ARTICLES.

Notes on the Physiography and Glaciology of North-East Carnarvonshire.

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I. INTRODUCTION.

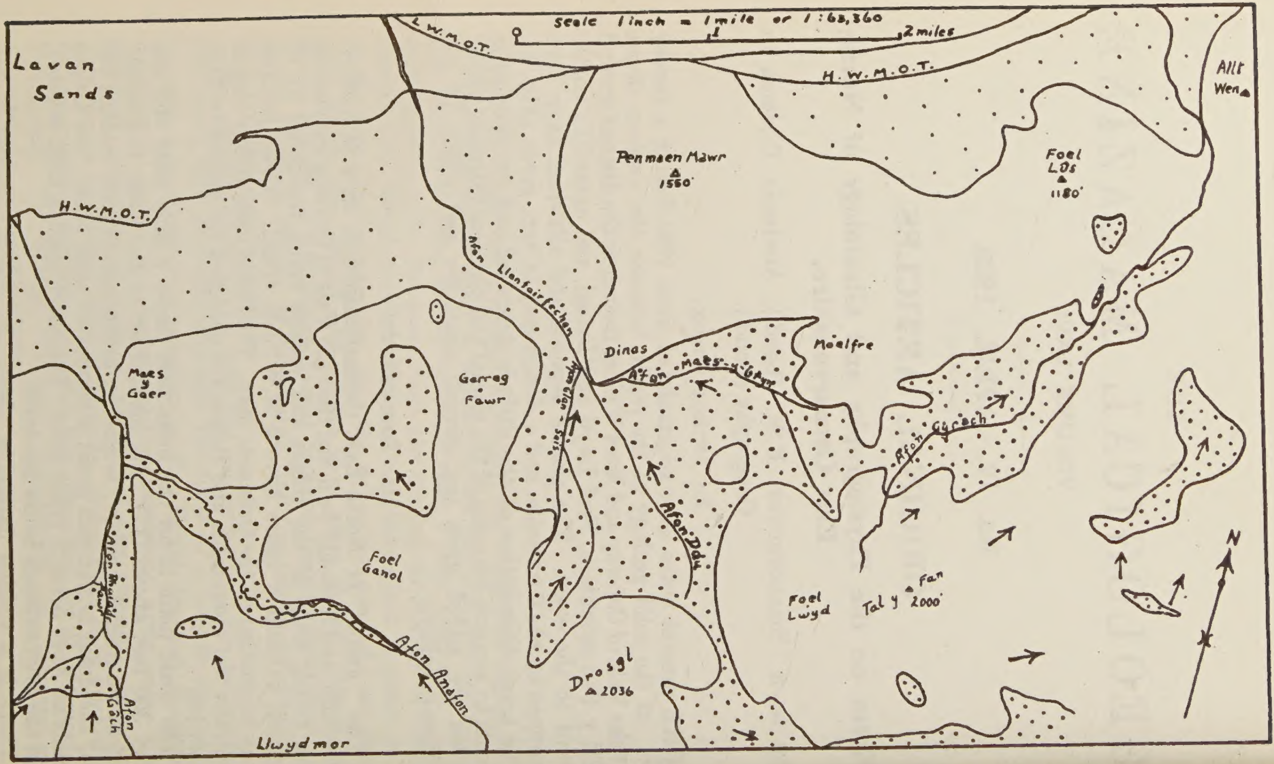
THE present notes have accumulated since 1923 during a survey of the solid geology of the region between the western slopes of the Vale of Conway and Moel Wnion, including the district around Tal y Fan mountain, Foel Lwyd and Drosgl, and extending northward to the coast. The glacial deposits and alluvium have been mapped on the 6 in. scale, and a sketch-map is here given (Fig. 1). The areal distribution of the drift is described and an attempt is made to account for some of the glacial and physical features. Some notes are added upon the general character and origin of the Conway Valley.

II. TOPOGRAPHY.

The "grain" of North-East Carnarvonshire is in a N.E.–S.W. direction, and it should be noted that the Vale of Conway cuts across this trend, some of the ridges and valleys being truncated by it. Several subsidiary spurs have a N.W.–S.E. trend. These features may be studied on the Ordnance Map. The broad upland depressions between the mountains and ridges are occupied by extensive drift deposits.

The coast plain is for the most part under a mile wide and less than 300 feet above O.D. Its inclination to the shore is gradual, but by no means regular. Where no mountainous land reaches the sea, the coast is flat and great stretches of sand occur, the Lavan Sands at Aber being 3 miles wide. The coast plain is drift covered, and the drift extends below sea-level.

There is a sudden flattening above the 700 ft. contour in the


Scale 1 inch = 1 mile or 1 : 63,360
0
1
2 miles
Lavan
Sands
L.W.M.O.T.
H.W.M.O.T.
H.W.M.O.T.
Allt
Wen
Penmaen Mawr
1550'
Foel
Lŵs
1180'
Afon Llanfairfechan
Dinas
Moelfre
Afon Maes-y-bryn
Afon Gyrach
Afon Glan-Sais
Afon Ddu
Garreg
Fawr
Maes
y
Gaer
Foel
Ganol
Foel
Lwyd
Tal y Fan
2000'
Drosgl
2036
Afon Anafon
Afon Rhaiadr
Fawr
Afon
Gôch
Llwydmor
N

country to the east of Foel Lûs, above the Fairy Glen (see profile of the Afon Gyrach, Fig. 9). Dewey[1] notes that in western Carnarvonshire plains occur at 700 and 1,000 feet, and there seems to be some similarity in the east of the county. Thus, between Maes y Gaer and the Roman Road north of Foel Ganol is a wide tract over 700 feet and to the south there is a similar flattened area on the northward-projecting spur of Llwydmor.

Between the 1,000 and 1,250 feet contours is a wide area which extends over the whole district. Garreg Fawr and Dinas, and the vast drift-covered stretch to the south and east, part of Penmaenmawr mountain, Foel Lûs, and a tract in the upper Afon Gyrach, Cefn Maen Amor, and the broad depression of the Afon Tafalog all lie between the 1,000 and 1,250 feet levels. There is also a broad area including Moelfre and Cefn Côch between the 1,250 and 1,500 feet contours north of Tal y Fan, which is possibly of similar origin to the 1,250 ft. platform around Snowdon, supposed by Professor Gregory to be of Pliocene age.[2]

III. Distribution of the Drift.

The map (Fig. 1) shows the areas where the thick masses of drift occur. It will be understood that irregularly distributed groups of boulders occur all over the district, and the drift is only shown where it is of sufficient thickness to obscure totally the solid geology. The arrows indicate directions of ice movement, which are determined by such evidences as striated surfaces, roches moutonneés, sources of erratics, and contour of the land. Heavy mineral separations show that on the higher parts the mineral assemblage is limited, whereas near the coast, owing to admixture with material foreign to the district, contamination sets in and the list of minerals is consequently augmented. It is hoped to discuss the mineral assemblages in another paper.

The work demonstrates that the high-level mountain drift is almost certainly of Welsh origin, and was formed by ice sheets which radiated outwards from Foel Fras and Carnedd Llewelyn. The evidence favours the view that the northern ice did not penetrate in bulk southwards beyond the coastal belt.

A. The Mountain Drift.

The thick deposits of mountain drift occur in the region mapped in four main areas, namely,

(1) In the valleys of the Afon Anafon and the Afon Rhaiadr-fawr.

(2) In a broad area north of Foel Lwyd and Drosgl, extending to Garreg Fawr on the west and Moelfre on the east.

(3) In the valley of the Afon Gyrach north of Tal y Fan.

(4) In the broad valley of the Afon Tafalog south of Tal y Fan.

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[1] H. Dewey, "On the Origin of some Land-forms in Carnarvonshire, North Wales," Geol. Mag., 1918, p. 149.

[2] J. W. Gregory, "The Pre-Glacial Valleys of Arran and Snowdon," Geol. Mag., 1920, p. 160.

In the case of the last three the drift areas have many points in common. Each occurs in an upland depression with a steep descent to lower land at the edge of the mountainous country. The main pre-Glacial drainage lines were similar to what they are at present, and it is well known that these valleys were excavated when the land stood at higher elevation than it does now.[1] The post-Glacial streams are to-day actively removing the drift from their valleys, some of which are choked with an enormous thickness of detritus.

Each of these mountain drift areas will now be described in detail.

(1) The Afon Anafon and Afon Rhaiadr-fawr.

The Afon Anafon flows from Llyn-yr-afon on the north-east of Foel Fras. This lake has all the characteristics of a typical corrie lake; it is surrounded by a steep cwm wall and has an outflow over scattered drift. Perhaps the best position to observe the lake as a whole is from the summit of Pen Bryn-dû, when the area occupied by the lake is seen to be cut out in the smoothly graded lower slopes of Foel Fras, resting well above the drift-floored Afon Anafon valley.

The narrow valley-deposit broadens out when traced downstream into a roughly triangular area south-east of Wern-y-Pandy. Eastwards this drift is continuous with a drift-covered area north of Foel Dduarth and west of Garreg Fawr, which is mostly marshy ground covered with local boulders. The west slopes of Foel Dduarth are too steep for any thick deposit of drift to occur.

On Meuryn Isaf occurs a high-level deposit of drift. This covers the fairly flat top of a northward projecting spur of Llwydmor Bâch, and rises to over 1,000 feet in the south but descends to 700 feet in the north, where it becomes continuous with the valley drift of the Afon Anafon. The deposit appears to rest as a thin cover, and consists of boulders of fine and coarse tuffs, grits, and basic igneous rocks, the distribution of which is very capricious. On the sketch-map (Fig. 1) the deposit is only indicated where thickest. Many pale green irregular and sub-angular boulders of a decomposed basic rock occur plentifully scattered on the west slopes of Meuryn Isaf, 300 yards east of Nant, and although these may be of glacial origin, it is considered more probable that they represent the outcrop of the south-westward continuation of the intrusive sills of Wern-y-Pandy. The valley drift of the Afon Anafon joins that of the Afon Rhaiadr-fawr by Bont Newydd.

The Afon Gôch rises in a broad drift-covered valley of Cwm-yr-Afon Gôch and descends some 250 feet over the ledge of Creigiau Rhaiadr Fawr into the drift-filled Aber valley. To the west the

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[1] See T. Codrington, "Note on a submerged and glaciated Rock-valley recently exposed to view in Carmarthenshire," *Q.J.G.S.*, vol. lviii, 1902, pp. 35–6.

Afon Bâch falls over the same ledge at Rhaiadr Bâch. The ledge[1] is due to an outcrop of resistant granophyre and its effect is clearly shown on the river profile (Fig. 9).

At the foot of the Falls at the head of the Aber valley occurs a thick deposit of drift of morainic character, cut into by the streams, and although most of the material examined seemed to be of local origin, it is suggested that the moraines may represent a stage when a tongue of the northern ice sheet projected southwards up the Aber valley. It is probable that the Cwm-yr-Afon Gôch was occupied by local ice, the ledge of Creigiau Rhaiadr Fawr being partly in the nature of a step. Lake[2] considers from evidence of a delta on Moel Wnion that at one stage during the Glacial Period the sea margin rose to 1,100 feet above its present level, and hence must also be considered the possibility that the precipice was for some time a sea cliff at the head of a fiord-like inlet.

The floor of the Aber valley from the Falls to the coast is drift-covered. The thin layer of drift between Aber village and Bont Newydd gradually broadens out southwards. West of Nant a post-Glacial gorge over 50 feet deep and a quarter of a mile long has been cut through the drift into cleaved slaty mudstones on the west side of the valley. Lowe and Davies[3] state this gorge to be 90 feet deep at one part. At Wern-gôch the drift is about a quarter of a mile wide over the floor of the valley, but south of this it suddenly broadens out into an almost square area nearly half a mile across. The drift is here thicker, and takes on a somewhat different character, being hummocky and drumlin-like, with some crude conical hills. Two excellent sections of the drift occur at the foot of the Falls on the western concave slopes above the stream meanders. The deposit is composed of stiff brown and grey clay, with many well-worn small and medium sized boulders of local origin. The main drift keeps below the 700 ft. contour, but much angular talus litters the lower slopes of the precipitous cliff at Marian Rhaiadr-fawr. Two well-formed elongated moraine-like mounds occur here, one on each side of the stream, the larger elongated east–west along the foot of the precipice just west of the Falls, and the other smaller mound with a north–south alignment. Two similar moraine mounds occur about a quarter of a mile to the west, one just west of the Afon Gam and the other between the Afon Gam and the Afon Rhaiadr-bâch. The mounds are about 300 yards long. The Afon Gam has cut a steep valley in the cleaved slaty sediments, and the cliff characteristic of the edge of the igneous rock is absent. The drift filling this valley is composed of local boulders in a stiff blue clay charged heavily with fragments of slates and mudstones. The valley is steepest on the south-east side, where the slaty mudstones rise towards the igneous rock. The steep slopes and the clayey nature of the boulder clay, combined with the present heavy rainfall, have caused landslips, the debris of which the stream is now rapidly removing.

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[1] See N. L. Silvester, "The Igneous Complex of Y Foel Fras, Caernarvonshire," Geol. Mag., 1922, pp. 134–9, and A. Heard, "Note on the Llwydmor Bâch Granophyre," Geol. Mag., 1922, pp. 358–61.

[2] P. Lake, "On Hill-slopes," Geol. Mag., 1928, p. 114.

[3] W. B. Lowe and I. E. Davies, "The Geology of the District between Conway and Aber," *Proc. Llandudno and District Field Club*, 1918, p. 52.

(2) North of Foel Lwyd and Drosgl.

An extensive deposit of mountain drift occupies the area north of Drosgl and Foel Lwyd. On the west it extends as a broad marshy flat over Ffrîdd Newydd and Ffrîdd Arw, flooring the valley of Gors Dwmpathog between Drosgl and Yr Orsedd. Llanerch Fedw is comparatively free from drift, but the deposit extends to the east over the old Roman Road and through the pass of Bwlch Ddeufaen, curving to the north of Foel Lwyd, causing more than a square mile of marshy ground around Maes y Bryn and Ffrîdd Forfudd. To the north the drift covers the area just south of Bryniau Bugeilydd, and flanks the slopes of Waen Llanfair o Cors y Carneddau. From thence the deposit stretches westwards a quarter of a mile south of Clip yr Orsedd and banks itself up against the steep south-east slope of Dinas. Part of this drift area is shown in the

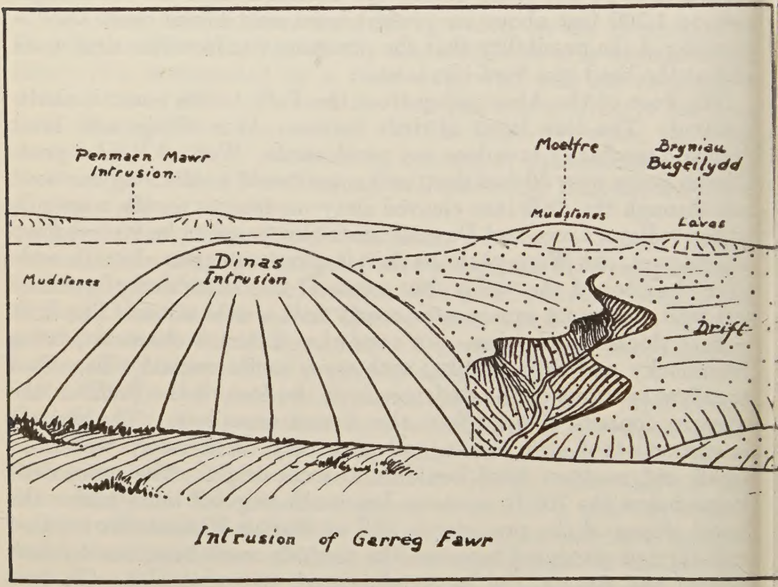

Fig. 2.—Diagram to show the steep post-Glacial valley excavated in the drift by the Afon Maes y bryn, and the deep valley between Garreg Fawr and Dinas. Looking east.

block diagram (Fig. 2). The whole area is drained by three streams, which rise on the margins of the drift.

The Afon Glan-Sais flows northwards from the foot of Drosgl to the south-west foot of Dinas, excavating a valley over 40 feet deep without cutting through the drift. The Afon Ddu flows to the same point in a direction north-west from Bwlch Ddeufaen, excavating a similar post-Glacial valley. The stream has cut a gorge into the underlying lavas at its source. The post-Glacial valley rapidly becomes over 50 feet deep downstream, and a quarter of a mile south-east of Camarnaint the stream is 100 feet below the general surface of the drift with no solid rock exposed beneath. However, just east of Camarnaint solid igneous rock is exposed on the east side of the stream, with a layer of boulders where the clay rests on the igneous rock, and a cliff of stiff brown boulder clay above.

The Afon Maes-y-bryn rises on the drift on two sides of Bryniau Bugeilydd, and flows with a gentle gradient to the 1,000 feet contour, when it begins to cut a gorge which rapidly increases in depth downstream. Erosion is here so rapid that steep cliffs of unvegetated drift occur on the concave banks of the stream meanders. 350 yards south-east of the summit of Dinas an isolated mass of igneous rock is exposed in the stream bed beneath the drift, through which the stream has cut a narrow gorge. Below this exposure the valley excavated in the drift is approximately 100 feet deep. The stream cuts into the Dinas igneous mass at Y. Teiryd, where it joins the Afon Ddu, and just farther down-stream the Afon Glan-Sais. The three united streams then flow north-westwards as the Afon Llanfairfechan along the steep drift-choked valley between Garreg Fawr and Dinas. Sargent[1] has suggested that these two intrusive masses are two separate plugs of igneous rock, with soft shales between, through which the stream has cut, the stream apparently having worked downwards along the eastern slope of Garreg Fawr. Detailed mapping has, however, failed to reveal mudstones or shales between the igneous masses, but intrusive rock has been revealed along the stream bed suggesting that the two masses are joined beneath the thick deposit of drift. It is possible that the gorge occupies the site of a fault which would be a northwards continuation of the Bwlch Ddeufaen fault.

(3) The Afon Gyrach.

The Afon Gyrach flows from the drift-covered northern foot of Tal y Fan north-eastwards between Cefn Maen Amor and Craig Hafodwen, through the Fairy Glen at Capelulo and into the sea by Dwygyfylchi. In the upland region, between its source and the head of the Fairy Glen, the river has cut a deep post-Glacial valley in the mountain drift, leaving small lateral hanging valleys 10 feet deep along the east side of the stream course above the Fairy Glen. The mountain drift is a typical boulder-clay with boulders from the south, and, where thin enough for observation, its character is closely related to the underlying solid rock. Just east of Red Farm, for example, it is almost completely made up of small pieces of lava and mudstone with a ground-up meal of the same rocks.

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[1] H. C. Sargent, "The Penmaenmawr Intrusions," GEOL. MAG., 1915 p. 17.

The drift occupies a broad shallow marshy depression about a mile wide between Cefn Maen Amor and Cefn Llechen, on the east, and Cefn Côch, Ffrîdd Wanc and Craig Hafodwen on the west. The projecting lobes shown on the drift map mark the routes of stream courses. North of Tal y Fan the mountain drift extends as a thick deposit from a height of 1,200 feet, and comes to an end above the coastal slopes at a height of 700 feet above O.D.

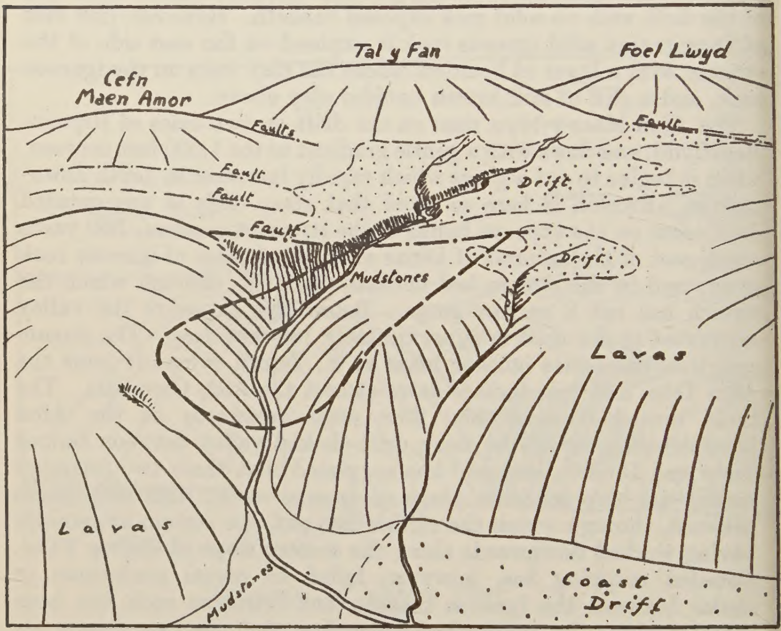

Fig. 3.—Diagram to show the relationship of the Afon Gyrach and the drift to the topography. Looking south. The thick broken line represents the boundary of the mudstone anticline, surrounded by overlying lavas.

The upland drift ends abruptly just above the Fairy Glen, the rapidity of erosion at the waterfalls having caused its early removal. At this point the stream makes a sudden descent from the upland, and falls over a series of minor cascades into the steep gorge-like valley to the north. (See river-profiles, Fig. 9.) This valley is for the most part excavated along the axis of a strong anticline in easily eroded Lower Llandeilo mudstones, and the consequent vigorous erosion has been facilitated by the comparatively rapid late Tertiary uplift. The waterfalls at the head of the Fairy Glen are due to an east-west fault, which brings up the southern end of the mudstones into juxtaposition with the faulted scarp of the lavas. At Capelulo, a quarter of a mile to the north, the stream cuts through a belt of hard rhyolitic lava with slight narrowing of the gorge, and the valley then suddenly opens out on to the broad coast plain. The abrupt ending of the mountainous land against the coast plain is here probably due to a westward extension of the Sychnant fault. The course of the Afon Gyrach, and the main features connected with the distribution of the drift and the origin of the Fairy Glen are shown in the accompanying diagram (Fig. 3).

To the east of Cefn Maen Amor a separate elongated patch of mountain drift occurs. It stretches from Maen Hir in the north, where the deposit covers an area a quarter of a mile wide from east to west, to Maen Penddu, about a mile to the south. For the greater part of its area it covers a shallow north-south valley excavated in the sedimentary series, mainly grits and mudstones, between the rhyolitic lavas of Cefn Maen Amor on the west and the tuffs and dolerites of Craig Celynin, St. Celynin's Church, and Cerrig y Ddinas on the east. The deposit is composed of local boulder clay and boulders of grits, tuffs, and basic rocks, some of large size, the main source of which lay to the south and west, but one well-rounded boulder of igneous rock west of Cae Defeitty contains large patches of augite and white felspars and is foreign to the immediate district.

A narrow elongated patch of drift about a quarter of a mile long in an east-west direction occupies the transverse gulley between Craig Celynin and the dome-like dolerite hill to the south. The drift extends eastwards down the Conway valley slopes, curving slightly northwards to Ffrîth-Bulkeley, and occupying a stream-covered marshy depression. It is probable that the igneous masses of Craig Celynin and the hill to the south are continuous beneath this drift.

(4) The Afon Tafalog.

This stream rises to the east of Drosgl at the junction of the lavas of Ffrîdd Cwm-Ithel and the superincumbent drift, and flows eastwards through a broad drift floored valley between Foel Lwyd and Tal y Fan on the north and the rounded summit of Pen y Gaer and Pen y Gader on the south. The drift is composed of typical buff and brown till, with local boulders. The stream has cut through the drift a deep post-Glacial gorge over 50 feet deep, which gradually deepens eastwards and is conspicuous owing to the lack of vegetation on the steep brown cliffs of boulder clay. The thick drift-mass lies for the most part between 1,000 and 1,250 feet above O.D.

B. The Coastal Drift.

This deposit, stated by Ramsay to be of marine origin,[1] extends along the coast except where headlands project into the sea, as at Penmaenmawr and Penmaenbach. Beyond the coast-line, however, are extensive deposits of sand, the Lavan sands extending for over 3 miles out beyond Aber, and again at Conway Marsh. Hall[2] mentions an old structure or hall, now 2 miles out to sea, and asserts that the coastline was much farther north even within the historic period. Mellard Reade[3] has described some sections of the coast drift at Llanfairfechan and Penmaenmawr, and states that ice and snow descending from the mountains may have played some part in its formation.[4] The west shore of Llandudno is composed of dune sands, which are most likely in part of glacial origin, and the same is true of the sands between the Great and Little Orme. Petrological examination of the coastal sands from these localities, as well as from west of Penmaenbach, Llanfairfechan, and Aber proves the deposits to be of striking similarity.

The coast drift at Aber ends in a line of low cliffs and salt marsh, and at Glan-y-Mor, Lowe and Davies[5] mention the presence of tree stumps below high tide mark, suggesting slight recent subsidence. The drift is occasionally thicker where it borders the mountains, owing to the talus derived from the latter, and this may show oblique bedding. Good sections of the coastal drift are found where the Afon Aber leaves the Aber valley, just by Pen-y-bryn. The deposits comprise well-graded sands, gravels, and clays, and false bedding is exhibited. The deposit affords evidence of rapid deposition under shallow water. Large boulders are very uncommon. To the east the coastal belt is less than a mile wide at the Gas Works. The drift ends against the cliffs at between 300 to 400 feet above O.D. north of Llŷs-y-gwynt Covert, between which and Coed Gorddinog it curves up the Nant y Felin-fâch valley to join the broad high-level drift area north of Foel Dduarth. At Coed Tan-yr-allt, the coastal drift ends at under 200 feet above O.D.

At Llanfairfechan the coastal drift covers the lowland to a height of about 500 feet on the west flanks of Penmaenmawr, but here it is much obscured by talus. Mudstones are visible on the path by Tan-y-graig, and east of this and along the south of the mountain, drift is absent for some distance.

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[1] A. C. Ramsay, "On the Superficial Accumulations and Surface Markings of North Wales," *Q.J.G.S.*, vol. viii, 1852, p. 373.

[2] C. R. Hall, "Ancient Coastline of North Wales between the River Dee and Anglesea," *Proc. Lpl. Geol. Soc.*, Session 6, 1865, pp. 7–19.

[3] T. Mellard Reade, "The Drift-beds of the North-West of England and North Wales," part ii, *Q.J.G.S.*, vol. xxxix, 1883, p. 112.

[4] T Mellard Reade, "The Drift Deposits of Colwyn Bay," *Q.J.G.S.*, vol. xli, 1885, p. 106.

[5] W. B. Lowe and I. Davies, "The Geology of the District between Conway and Aber," *Proc. Llandudno and District Field Club*, 1918, p. 89.

The coastal drift fills the lower part of the broad valley of the Nant yr Iâr extending eastwards to Glan-yr-afon, and the eastward margin of the deposit curves southwards to the north-west foot of Dinas. Excellent exposures of this drift occur along the Afon Llanfairfechan, on the right bank south of Ty'n-y-llwyfan, and in the gravel-pit by the buildings. On the west, the upper limit of the thick drift follows the 500 feet contour along by Tan'rallt-uchaf, an excellent section of the deposit being exposed in the gravel pit a quarter of a mile to the east-north-east of this farm. South of this point the drift extends up the eastern slopes of Garreg Fawr to over 1,000 feet above O.D. in half a mile, where it becomes admixed with the mountain drift. Between Garreg Fawr and Dinas, the steep valley of the Afon Llanfairfechan where the stream cuts through the igneous rock is choked with drift, which extends up the western slopes of the valley to 800 or 900 feet, but barely reaching 600 feet on the steep west slope of Dinas. The coastal drift is again well seen in a low cliff 15 feet high west of Penmaenbach. Here the deposit is clayey and of a dark reddish-brown colour, with broken stones and small rounded boulders. The heterogeneous nature of the drift is well displayed in the bank of boulders and pebbles between Penmaenmawr and Penmaenbach. Some large lava boulders, more than 3 feet across, occur with plentiful smaller boulders of various types of intrusive rocks, grits, and tuffs, together with a few Carboniferous limestone boulders, all of which were derived from the immediate hinterland. Brecciated lava and mudstone pebbles are present from the base of the lava flows, such rocks having been located in situ at the Fairy Glen and on Drosgl. There are also present rocks from a northern source. Boulders and pebbles of Eskdale and Criffel granite occur along this coast.

IV. ROCK SURFACES AND BOULDERS.

Numerous boulders of local rocks cover the slopes of Drosgl. On the summit of Pen Bryn-dû occur scattered blocks of massive white quartz, evidently connected with the lavas. Mapping shows that the lower boundary of the rhyolitic lava series runs just to the west of the occurrence, and curves eastwards across the Pen Bryn-dû-Foel Dduarth ridge, and the latter summit of cleaved mudstones has no quartz blocks. Hence they may be residual blocks derived from the weathering of the lavas, which frequently contain massive quartz veins, and it is unnecessary to assume that they have been transported from Drosgl by ice as supposed by Lowe and Davies.[1] Local patches of boulders of basic rock, such as occur to the south of Maes y Gaer, probably represent the weathered surfaces of unexposed intrusive rocks below.

On Cefn Maen Amor is a group of large boulders of tuffaceous grit, which although possibly brought together by man, are no doubt

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[1] W. B. Lowe and I. Davies, op. cit., p. 88.

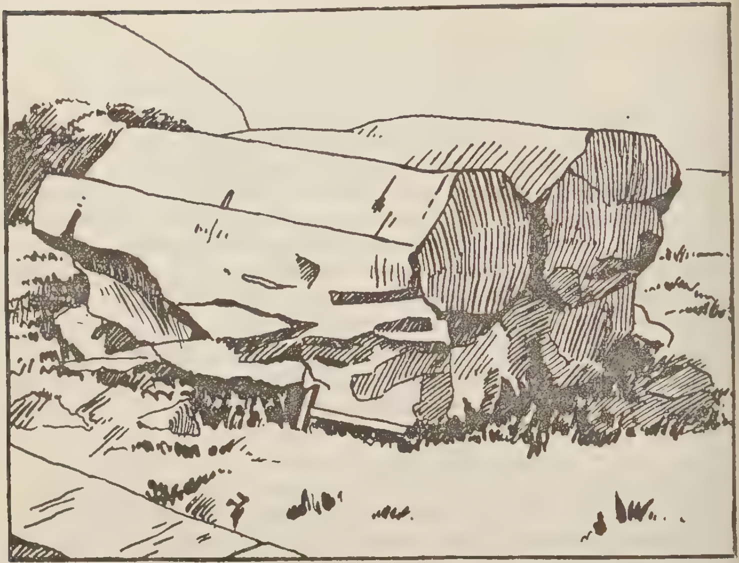

Fig. 4.—Erratic block of columnar dolerite resting on rhyolitic lavas. North of Maen Penddu. (Sketched by the author from a photograph.)

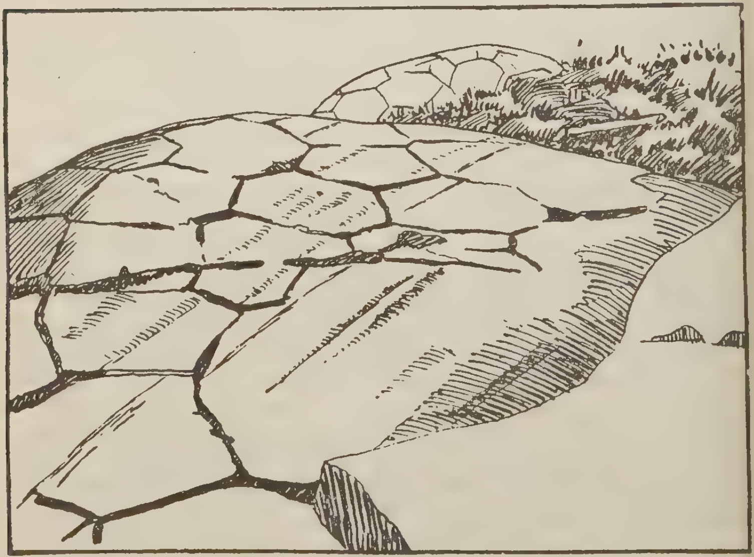

Fig. 5.—Striated and smoothed surfaces of columnar dolerites. West side of knoll south of Craig Celynin. (From a photograph.) The striations are parallel with the Conway Valley.

rratic blocks. They form a conspicuous landmark owing to their uge size and to the fact that they rest on the smooth upland surface f the rhyolitic lava series in a spot comparatively free from other oulders of consequence (Fig. 7). Their angular edges suggest that hey have not moved far from their place of origin, and they might ell have come from a band of similar rock which occurs between he upper and lower lava series from just south of Sychnant to Drosgl. t a point 380 yards west of the summit of Craig Hafodwen, at a eight of over 900 feet above O.D., occurs a fair-sized erratic block f a garnet-bearing felsitic rock, similar to a rock seen in situ by the riter near Scawfell in the Lake District.[1] Hence the northern ice eached at least this height and banked itself up against the coastal lopes, and it is interesting to note that Ramsay considered the orthern ice sheet to have passed over Penmaenbach, which has in onsequence a "strikingly moutonnée" shape.[2] Mackintosh,[3] lso, has recorded a Scottish granite from 1,900 feet above O.D. on Moel Wnion. Dinas has a somewhat similar shape (Fig. 2). Foel Lûs, lso, has a beautifully rounded summit which may have been influenced by the ice, but it is more probable that its form is due to ts anticlinal dome-like structure. The rounded summits of both Moel Wnion and Maes y Gaer are also due to an anticlinal structure.

A rare type of boulder in this locality is that of the columnar dolerites. One of these is here figured (Fig. 4). It shows well-marked columns of dolerite resting in a horizontal position on the rhyolite lavas. It is evident that these erratics have not travelled far from the point of origin. Such columnar intrusive rocks occur in situ on Cerrig y Ddinas, Craig Celynin, and Tal y Fan, and the block figured probably came from Tal y Fan, in which case it has not travelled more than a mile. The block also furnishes a clue to the direction of ice movement. This is of importance, since the surface of the rhyolitic lavas of Cefn Maen Amor, partly owing to the intense cleavage, give very little evidence, but the scattered boulders examined are of local origin.

The dolerite intrusions of Cerrig y Ddinas and Craig Celynin give by far the best examples of glacial action on bare rock surfaces over the whole region, and this might be expected from their position, since they must have stood as a resisting buttress in the path of the great northward-flowing glacier of the Conway valley (Fig. 6).

[1] A micro-section confirmed this determination. The rock consists chiefly of a microfelsitic groundmass with much calcite, secondary muscovite and quartz, the latter occurring in thin veins with some chlorite, decomposed orthoclase and plagioclase with pericline twinning, and pink garnets, 1 to 3 mm. diameter.

[2] A. C. Ramsay, "Geology of North Wales," *Mem. Geol. Surv.*, 2nd ed., 1881, p. 273.

[3] D. Mackintosh, "Additional Discoveries of High-level Marine Drifts in North Wales, with Remarks on Driftless Areas," *Q.J.G.S.*, vol. xxxviii, 1882, p. 193.

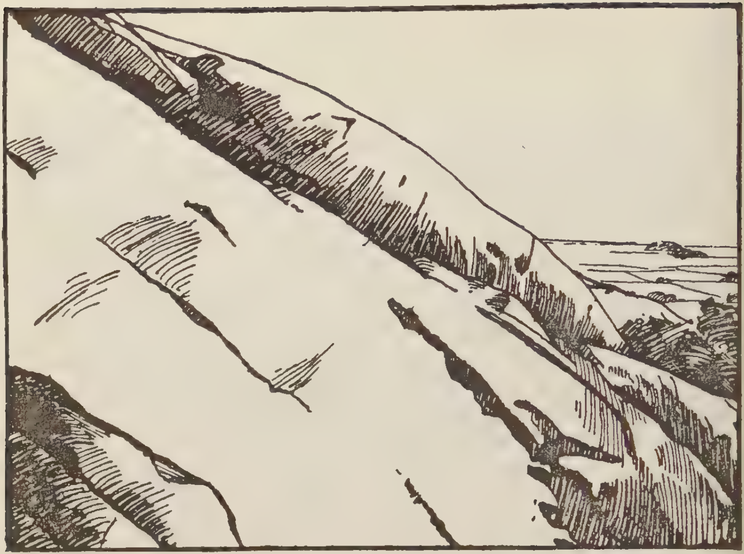

FIG. 6.—Rock surfaces smoothed and polished by the Conway Valley glacier. East side of Cerrig y Ddinas, looking north. (From a photograph.)

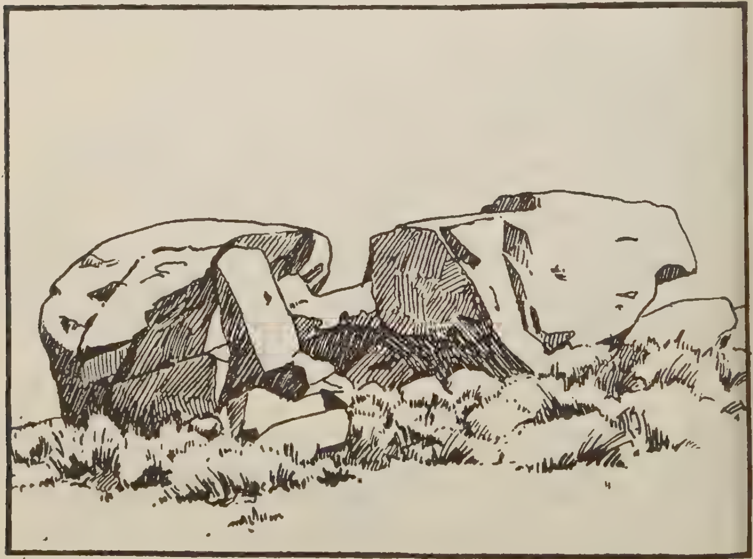

FIG. 7.—The Cefn Maen Amor boulders. Huge erratic blocks resting on rhyolitic lavas.

Craig Celynin rises steeply on the southern side above the drift-filled Afon Tafalog valley, which contributed ice from the west. This valley was occupied by a broad glacier which flowed eastward from the nevés of Foel Fras. Probably during the period of maximum glaciation Tal y Fan was covered by the ice, but later the highest ridge was left uncovered, its rough arête-like form being then accentuated. The shape of the mountain is due to its geological structure, and its dominant feature is a broad sill of dolerite which dips south-east and forms a scarp just north of the summit, the crest of the mountain approximately coinciding with the strike. The southern dip slope has glaciated rock surfaces and transverse gulleys down which ice flowed from the summit to the Afon Tafalog glacier.

East of Caer Bâch the dome-like hill of dolerite south of Craig Celynin is extensively glaciated and bare striated rock surfaces and roches moutonnées everywhere abound. The rock has frequently been eroded out along a north-south set of master joints. Interesting features are provided by the columnar dolerites on the western and southern side of the hill. The rock is exposed in planes at right-angles to the length of the columns, and striated roches moutonnées formed from them. The smoothed rocks, therefore, show all typs of cross-sections of 4, 5, and 6-sided columns, the cracks forming a network over the curved striated surface. Spheroidal weathering seems to have played some part in a few cases, but the well-preserved striations show that this process, if here operative, is very slow. A sketch of one occurrence with north-south striations is here reproduced (Fig. 5).

The eastern slopes of Craig Celynin are far more smoothed than the western and smoothed surfaces are still more marked on the east side of Cerrig y Ddinas. Glaciated surfaces occur at over 1,200 feet above O.D. on the former, and up to over 900 feet on the latter. It is obvious that the bulk of the ice occurring to the west was thinner owing to the greater elevation of the land and much of this ice must have come from local sources, whilst the Conway valley glacier, which caused the smoothed surfaces mentioned, had received many tributary ice streams higher up its valley ; indeed, it is probable that the glacier was already of considerable dimensions 12 miles up the valley after which it received glaciers from the nevés of Carnedd Llewelyn, Foel Fras, and Drum, by way of the Afon Ddu, Porth-Llwyd, Dulyn, and Tafalog valleys.[1] The Afon Tafalog glacier and the Conway valley glacier met and swept northwards just south of Craig Celynin and the already described knoll to the south, and hence there would be a local thickening of the ice and consequently more polishing and striating. The form of the ground and the striations indicate that a definite movement of ice, an offshoot of the main Conway ice-stream, took place northwards through the depression between Craig Celynin and Tal y Fan, depositing the boulder clay already mentioned in the valley between Cefn Maen Amor and Cerrig y Ddinas.

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[1] SeeA. C. Ramsay, " How Anglesey became an Island," *Q.J.G.S.*, vol. xxxii, 1876, p. 118, and *The Old Glaciers of Switzerland and North Wales*, London, 1860, p. 75. See also " Geology of North Wales ", *Mem. Geol. Surv.*, 2nd ed., 1881, pp. 272–3.

V. Note on the Conway Valley.

There is a general increase in height of the mountains of the Snowdon range westwards from Tal y Fan. Similarly there is an increase southwards in the heights of the chief summits towards Moel Siabod. Hence the mountain summits indicate a former plain which sloped upwards towards the south and west, out of which the present valleys were carved. The evidence favours Lake's view [1] that higher ground existed near the source of the Conway from which the young river flowed northwards. Post-Silurian earth movements [2] gave rise to north-east–south-west lines of weakness and in a direction at right angles to this, and the former is the general orientation of the western tributaries of the Conway. A north-south and east-west disturbance is suggested to be post-Carboniferous. These are the most common joint directions in the basic igneous rocks of the west slopes of the Conway valley from the estuary to as far south as Ro Wen, and hence the main valley itself has been affected by this disturbance.

The Conway valley is a north-south major feature which differs from the well-known north-west–south-east trend of the major valleys of Carnarvonshire and the north-south valleys of Arran.[3] This north-south feature extends southwards to Bettws-y-Coed, and is clearly related to the geological structure occurring for the greater part along the junction of Ordovician and Silurian rocks. The topography on the two sides of the valley is very different, the steep escarpment and rugged character of the west slopes contrasting strongly with the comparatively smooth uplands of the east (Fig. 8).

The minor south-west to north-east tributary valleys joining on the west have not yet been cut down to accordant grade, and hang with respect to the main valley, differing therefore from the tributaries on the Silurian rocks to the east. The streams of the hanging valleys are now rapidly adjusting their grades to the base-levelled main valley, erosion being exceptionally vigorous at the mouth of each hanging valley, where cascades and waterfalls occur over the lip. The

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[1] P. Lake, "Bala Lake and River System of North Wales," *Q.J.G.S.*, vol. lvi, 1900, pp. 230–1, abstract, and Geol. Mag., 1900, pp. 244–5.

[2] J. E. Marr and R. H. Adie, "The Lakes of Snowdon," Geol. Mag., 1898, pp. 51–2.

[3] J. W. Gregory, "The Pre-Glacial Valleys of Arran and Snowdon," Geol. Mag., 1920, pp. 150–1.

Afon Porth-llwyd,[1] Afon Ddu, Afon Dulyn, and Afon Tafalog are examples.

The river profiles (Fig. 9) illustrate the hanging relationship of the western tributaries. The profiles of the larger headstream tributaries of the River Conway, however, namely, the Llugwy, Machno, and Lledr, are accordant and their courses in common with the main river are confined to Ordovician rocks. Their drainage basins are much larger than those of the hanging south-west–north-east tributaries and we should therefore expect greater erosion along the main river. Again the rejuvenated Conway valley has been eroded after uplift along a line of tectonic weakness, whilst the hanging tributaries have had to cut through hard intrusive and volcanic rocks. These are absent in the Silurian on the east side of the valley and the country is lower owing to its less resistant nature. It is not sufficient to invoke the aid of glacial over-deepening to account for these hanging valleys,[2] although it may have been a contributory cause, and ice erosion may have been responsible for the truncated spurs of the west slopes of the Conway valley, especially when it be remembered that the north-flowing Conway glacier must have been of considerable dimensions. It is probable also that after the period of maximum glaciation, protecting

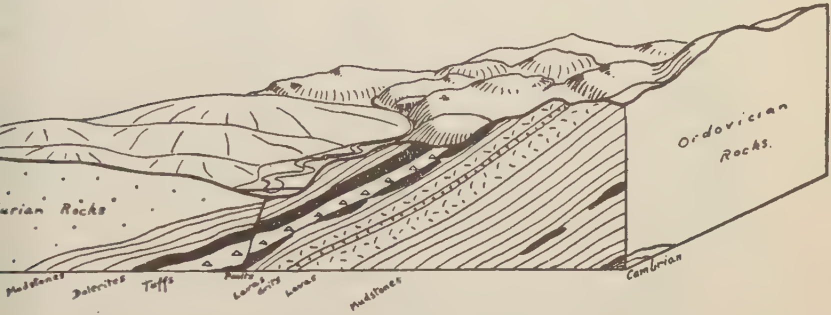

Fig. 8.—Generalized block diagram to show the relationship of the Conway Valley to the geological structure.

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[1] The course of the Afon Porth-llwyd has been adequately described by Professor W. G. Fearnsides and W. H. Wilcoxson, " A Topographical Study of the Flood-swept course of the Porth Llwyd above Dolgarrog," *Geogr. Journal*, vol. lxxii, No. 5, Nov., 1928, pp. 401–19. See also Dolgarrog Dam Disaster, report of a Committee, *Rep. Brit. Assoc.*, 1927, Leeds, pp. 276–80.

[2] T. J. Jehu ascribes this discordance to be entirely due to over-deepening by moving ice. " A Bathymetrical and Geological Study of the lakes of Snowdonia and Eastern Carnarvonshire," *Trans. Roy. Soc. Edin.*, vol. xl, part ii, 1902, pp. 460–1. For a similar case see also B. Smith, " Glaciation of the Black Combe District," *Q.J.G.S.*, 1912, vol. lxviii, pp. 402–47. See also W. M. Davis, " Glacial Erosion in North Wales," *Q.J.G.S.*, vol. lxv, 1909, pp. 281–344.

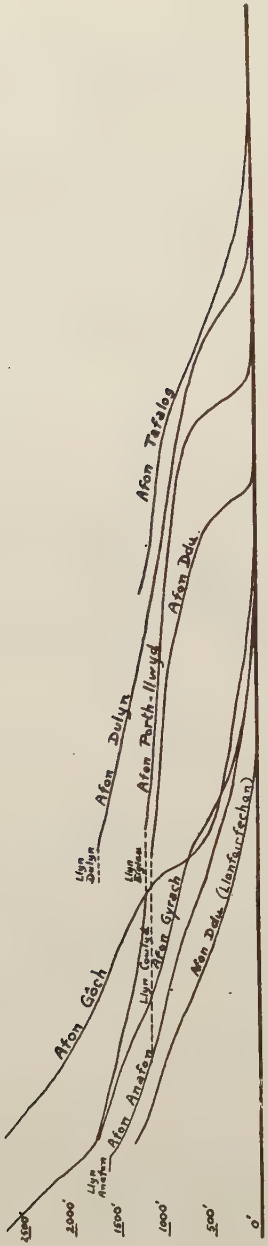

FIG. 9.—River Profiles. Horizontal scale 1 in. = $1\frac{1}{2}$ miles or 1 : 95,040. The four profiles on the right are tributaries of the R. Conway.

ice lingered on the higher land to the west of the Conway valley, whilst active erosion was proceeding along the valley-floor thereby causing an augmented discordance between the main and lateral valleys.

Faulting and brecciation are common along the Conway valley. Gregory[1] has suggested that the major valleys of the rectilinear system around Snowdon may occur along shatter belts due to tension during Pliocene uplift; broader valleys would be formed where tension is relieved by multiple faults. Marr has described valleys which are due to intense faulting.[2] Transverse faults are very numerous along the west slopes of the valley and 6 inch mapping has shown five such faults to occur in less than a mile. Miss Elles[3] has demonstrated the intense faulting and thrusting in the Conway district and has placed a fault along the Conway River between Conway and Deganwy. It is probable that for several miles the Ordovician-Silurian junction is a faulted one as shown on the old hand-coloured Geological Survey 1 inch map. Sedgwick[4] put the age of this fault as post-New Red Sandstone.

The rocks along these faults are frequently intensely shattered and brecciated and masses of quartz occur along them, which have led to frequent trials for minerals. East–west transverse faults cut the steep slopes of Cerrig y Ddinas and are marked by small valleys, the size of which bears a relationship to the intensity of the faulting. Unfortunately a wide deposit of drift and alluvium covers the floor of the Vale of Conway and thick deposits of wooded talus and drift are banked against the foot of the steep west slopes in many places, but the evidence obtained suggests that intense faulting and shattering exist beneath the superficial deposits.

In conclusion, I wish to record my thanks for the facilities afforded by the Geological Department at Birkbeck College during the course of this work, and especially to Mr. G. M. Davies for many useful suggestions.

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[1] J. W. Gregory, op. cit., pp. 154–5.

[2] J. E. Marr, "The Influence of the Geological Structure of the English Lakeland upon its present features," *Q.J.G.S.*, vol. lxii, 1906, pp. cii–cxxiii. See also J. E. Marr and R. H. Adie, GEOL. MAG., 1898, pp. 51–2.

[3] G. L. Elles, "The Relation of the Ordovician and the Silurian Rocks of Conway (North Wales)," *Q.J.G.S.*, vol. lxv, 1909, pp. 169–94.

[4] A. Sedgwick, "Outline of the Geological Structure of North Wales," *Proc. Geol. Soc.*, vol. iv, 1843, p. 222.

Notes on the Millstone Grit of the North Crop of the South Wales Coalfield.

By D. G. Evans, B.Sc., and R. O. Jones, M.Sc., F.G.S.

I. Introduction.

THE precise age of the Millstone Grit of South Wales has been in doubt for some years. Although it has been shown to be of Upper Carboniferous age, it has been uncertain whether the whole of the earliest part of the Upper Carboniferous is represented by deposits in southern Britain. Some part of the Millstone Grit of Pembrokeshire has been regarded, on the basis of its flora, as of Middle Coal Measure or Yorkian age (Goode, 1913, p. 272). Similar conclusions have been reached by Dr. R. Crookall concerning part of the Millstone Grit of Somerset (1925, p. 403). As yet, the flora characteristic of the Lanarkian of northern Britain has not been proved to be present in South Wales and elsewhere in south Britain. On the other hand, it has been argued that the absence of a Lanarkian flora does not necessarily imply an important break in the sequence, since recent work on the lamellibranch fauna of various British coalfields points to the conclusion that the lowest part of the Lower Coal Series of South Wales is of approximately the same age as the Lower Coal Measures of northern England (Davies and Trueman, 1927, p. 253).

The lowest beds of the Millstone Grit in some parts of South Wales have been correlated with the Pendleside Series of the north of England by the late Wheelton Hind (1909, p. 170). On the other hand, Mr. E. E. L. Dixon showed (Newport Memoir, p. 20) that in certain places along the East Crop of the South Wales Coalfield there is ample evidence of unconformity between the Grit and the Carboniferous Limestone. Subsequent work on this and other areas has established the wide extent of this unconformity (Haverfordwest Memoir, p. 151; Dixey and Sibly, 1917, p. 123; Dixon, 1921; Dixon and Pringle, 1927; George, 1927, p. 51), although it has not yet been shown to occur in all parts of South Wales. The results of the present research, which deals only with part of the North Crop of the Coalfield, indicate that the relationship of the Millstone Grit and the Avonian is one of unconformity along the whole of that area.

In recent years increased interest has been attached to the Millstone Grit of Britain owing to the work of Mr. W. S. Bisat on the goniatite zones of the Millstone Grit of the north of England (1924). Certain of these zones have been recognized in their proper sequence in Lancashire by Mr. W. B. Wright and others (1926). In several parts of South Wales several of these zones have been shown to be

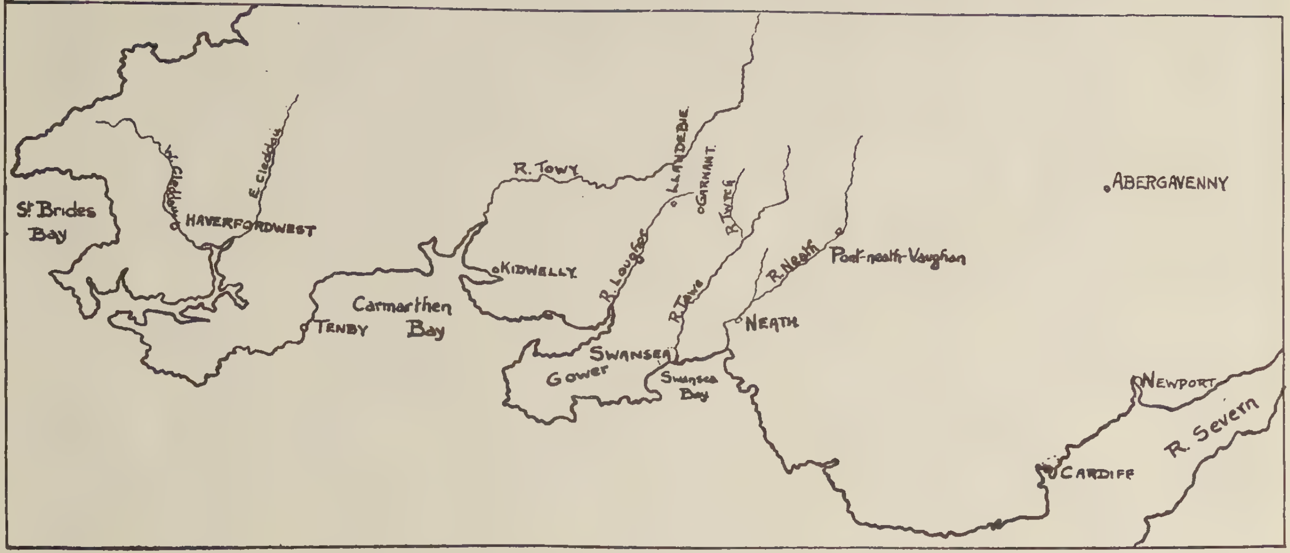

FIG. 1.—Sketch map of South Wales to show localities named in the text. (Scale approximately 11¾ miles to 1 inch.)

present (O. T. Jones, 1925; Kitchin, 1926; Abergavenny Memoir, p. 43; George, 1927).[1]

In this paper an attempt is made to determine the goniatite sequence in the North Crop of the South Wales Coalfield and to compare it with the sequence in the north of England.

II. General Stratigraphy.

For convenience in mapping, the Geological Survey Officers divided the Millstone Grit of the North Crop of the South Wales Coalfield into three groups which are traceable over a wide area. These divisions are:—

Farewell Rock.—Typically a white quartzite, but often a sandstone and sometimes replaced by shales in the west.

Shale Group.—Dark shales with thin coals and occasional impersistent sandstone bands.

Basal Grits.—Pebbly grits and quartzites with bands of shales.

In the western part of the outcrop (near Llandebie) the series becomes less sandy and the Farewell Rock becomes almost unrecognizable owing to its passage into shales (see also Trueman, 1924, p. 291).

The thickness of each subdivision and of the Millstone Grit as a whole varies considerably from east to west along the crop. The whole formation is thickest in the Ammanford district (1,200 feet) where the Farewell Rock is about 200 feet thick, the Shales about 500 feet, and the Basal Grits (with the Plastic Clay beds, about 50 feet thick at the base) are about 600 feet thick (Ammanford Memoir, p. 81). When these are traced eastwards each is found to diminish in thickness and in the Vale of Neath are found to be 150–200 feet; 100–150 feet and 80–100 feet respectively (Merthyr Memoir, p. 38). Still further eastwards this diminution in thickness becomes more marked, and at Abergavenny the thicknesses are respectively 40–80 feet, 80–100 feet, and 20–80 feet, giving a total of just over 200 feet (Abergavenny Memoir, p. 42). In the extreme west at Haroldston St. Issels there is lithological evidence of an unconformity between Millstone Grit and Carboniferous Limestone and the whole formation is very thin, being only 40 feet thick and consisting of quartzites at the base followed by thin fossiliferous shales (Haverfordwest Memoir, p. 151).

III. Description of Sequence.

It will be convenient to take first the sequence determined in the Vale of Neath, as more fossils have been obtained there.

(*a*) *Vale of Neath* (*Sychryd Valley*) (Six-inch maps, Breck., xlix N.E., Glam. x, N.E.).

Several tributaries of the River Nedd (Neath) flow across country formed by Millstone Grit, and along one of its tributaries, the Sychryd, some very good exposures are to be found.

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[1] On pp. 40, 53, 81, and 84, Dr. George refers to *Homoceras* aff. *proteum* being found near the base of the Millstone Grit on the North Crop. This form has been found in South Wales, but it is a long-range species and does not prove the *proteum* zone (R. O. J.).

The Quartz Conglomerate (Basal Grits) along this stream has been used in the making of Dinas fire-bricks and they have been quarried for that purpose at Coed-y-Ffyrnau. The quarry, about 600 yards up-stream from Pont-Neath-Vaughan (Pont-Nedd-Fechan), is mentioned by the Geological Survey Officers (Merthyr Memoir, p. 41) as it gives " an admirable view not only of alternations of quartz-conglomerate, grits, and shales, but of the sharp curve-up by which these strata pass from a dip of 15° to verticality on the flanks of an anticlinal ridge " (see also Merthyr Memoir, Plate II, Section 2, p. 91). A fault throwing Millstone Grit against Limestone runs along the bed of the river but " passes into the Limestone abreast of the quarry " (Merthyr Memoir, p. 41). For the rest of its outcrop to Penderyn the conglomerate rests naturally upon the Limestone.

Although the thin shale bands in the quarry face yielded no important fossils, somewhat higher shales on the side of the quarry contain comparatively numerous fossils in certain bands.

In some loose material on the quarry side (about 30 feet above the base of the Grits) fragments of *Orthoceras* and goniatites together with some brachiopods were found. Most of the fossils were crushed in well-bedded black shales, but a few goniatites and brachiopods were better preserved in a calcareous matrix. These proved to be *Martinia* sp., *Homoceras striolatum* (Phillips)[1], and a fish bone.

Goniatites were found in shale bands (which increase in thickness as the succession is ascended and so grade into the overlying Shale Group) a few feet above this loose material and up to the top of the Quartz Conglomerate; some of them were badly crushed, but they include *Homoceras striolatum* (Phillips) and *Reticuloceras inconstans* (Phillips).

Above the Quartz Conglomerate there are from 30 to 40 feet of shales which are not very well exposed; these have yielded very few specimens, all of which are badly preserved. A few have been identified as *R.* cf. *inconstans*. At about 40 feet above the base of the Shales there occurs a band of grit some 12 feet thick which forms a constant feature in the ravines of the local streams (see Merthyr Memoir, p. 38).

About 200 yards (due east) along the Sychryd is a waterfall caused by the above-mentioned grit band. At a short distance above this fall shales are exposed along the river side which are extremely fossiliferous. By far the most common form found here was *Gastrioceras crenulatum* Bisat. Some badly preserved specimens of the following were also found in the river bed: *Posidoniella* sp. and *Productus* sp. These shales are not well exposed on the slopes of Pencaedraen, but at a slightly higher horizon, about 20 feet above the grit band, some feebly preserved crushed specimens of cf. *Dimorphoceras* sp. have been found. The shales at this horizon have a reddish tinge. A few feet higher beds full of *Lingula* and also containing *Orbiculoidea* and *Sanguinolites interruptus* Hind are exposed.

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[1] While this paper was in the press a further account of the Millstone Grit succession has been published by Mr. Bisat ("The Carboniferous Goniatite Zones of England, etc.," *Congrès de Strat. Carb. Heerlen*, 1928, pp. 117–33). It is possible that some of the forms referred to in the present paper as *Homoceras striolatum* should be referred to the new species *H. eostriolatum* Bisat.

Higher exposures in these stained shales are also very fossiliferous and yielded a large number of goniatites, most of which, however, were badly preserved but have been identified as *Dimorphoceras* sp.

A short distance to the south-south-west of these last exposures, higher shales, probably near the base of the Farewell Rock, are seen in a small exposure 180 yards due west of Pencaedraen Farm and just north of the railway at the western end of Pencaedraen Tunnel. In the shales *Carbonicola* cf. *ovalis* (Martin) was found in abundance. It is interesting to note that the Geological Survey Officers (see Merthyr Memoir, p. 50) recorded *Carbonicola* from what appears to be an identical horizon at the eastern end of the tunnel.

The shales from this horizon to the base of the Farewell Rock have not yielded fossils at this locality, but similar shales in the north bank of the River Hepste, about a quarter of a mile north-west of Penderyn Church, were found by the Geological Survey Officers to contain goniatites which were recorded as *Glyphioceras bilingue* (Salter) but which seem to be *Gastrioceras* sp.

Some shales are exposed in the bed of the Sychryd some 100 yards downstream from the first-mentioned quarry. These shales belong to a faulted block and it is difficult to state their relation to the main mass. These shales were found to be very fossiliferous and contain *Reticuloceras reticulatum.* mut. γ Bisat, together with some badly-preserved specimens of *Gastrioceras* sp.

It is, therefore, probable that the Quartz Conglomerate in the Vale of Neath represents zone R_1 of the north of England, and the upper part (above the grit band) of the Shale Group represents G, while shales of R_2–G age are also exposed. The lower part of the Farewell Rock here is probably within the G zone (*G. listeri* zone ?), but owing to the unfossiliferous nature of this massive sandstone the age cannot be definitely determined.

In another tributary of the Neath, the Perddyn, the 12 foot grit band gives rise to a picturesque waterfall called Scwd Gwladys and in some shale at the foot of this fall the following freshwater fossils have been found in abundance: *Carbonicola* cf. *communis* Davies and Trueman and *Carbonicola* cf. *ovalis* (Martin) (see Davies and Trueman, 1927, p. 238).

(*b*) *Garnant (Cwm Pedol, Garw Valley, and Berach Valley).*

The Millstone Grit in this region forms the dip slopes of a barren part of the Black Mountains on the north of the Amman Valley, nd some excellent exposures of the Shales and Basal Grits are found n the Pedol and Garw Valleys. The Shales, however, appear to e far less fossiliferous than their finely-bedded character would uggest.

The Pedol, Garw, and Berach are mountain steams flowing outhwards into the Amman, which in its turn, flows westwards nto the Loughor. As these three streams flow along the dip of the rocks, which dip southwards at approximately 15°, higher beds of the Millstone Grit come in downstream (see Ammanford Memoir, p. 83).

1. *Garw Valley.*

The Basal Grits are not well exposed here but the lower beds of the Shales are to be seen at the head of the valley (Ammanford Memoir, p. 83). In one of these exposures on the left side of the stream *Carbonicola* cf. *ovalis* (Martin) was obtained in fair abundance.

In occasional outcrops of shales downstream attempts to find fossils have so far met with no success. The upper beds of the Shale Group form a cliff below the Llangadock Road at Craig-derlwyn (Ammanford Memoir, p. 83); above a sandstone band, near the base of this cliff, are shales with goniatites and occasional badly-preserved lamellibranchs. They are identified as *Gastrioceras subcrenatum* (Scholth.), *Pterinopecten* sp.,[1] and *Posidoniella* cf. *rugata* Jackson. Above this shale band occur the brown and olive green sandstones which are typical of the Farewell Rock in this area.

2. *Cwmpedol.*

This valley is about two miles west of the Garw. Shale bands in the Basal Grits are exposed at several places in the valley.

What appears to be the top shale band in the Basal Grits is exposed in the left bank of the river about 300 yards above Creigiau Farm, just below the sheep fold. This bed proved to be very fossiliferous and goniatites and lamellibranchs were found to be fairly abundant. They are identified as *Pterinopecten* sp., *Pterinopecten* cf. *speciosus* Jackson, *Posidoniella multirugata* Jackson and *Reticuloceras reticulatum* mut. β Bisat. The most interesting specimens were some very large examples of *R. reticuloceras* mut. β. Complete specimens with diameters up to 28 mm. have been found. At this diameter the forward projection of the lingua is 5 mm., the depth of the hyponomic sinus 12 mm., and the transverse striae 4–5 per mm. on the linguae, all of which measurements agree closely with those given by Bisat in his table (1924). Fragments of still larger specimens with whorl-height varying from 13 mm. to 23 mm. which had a forward projection of lingua from 5 mm. to 7 mm. respectively and a depth of hyponomic sinus from 5 mm. to 15 mm. respectively, were found. No such large forms are recorded from Yorkshire and Lancashire.

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[1] This form resembles *P. papyraceus* in all its characters except the number of radii, having 56 as compared with about 79 in the latter (D. G. E.).

Shales are exposed in the valley and in the valleys of the little tributaries flowing into it, further south, but fossils are particularly rare, a few specimens of *Lingula* cf. *mytiloides* Sowerby being obtained at one exposure high up in the shales.

Further south, about 250 yards north of Cwmpedol Farm, is a sandstone band, and in the shale band immediately above this a few fossils were found, viz. *Posidoniella* cf. *laevis* (Brown) and *Edmondia* sp.

Above this occurs a group of quartzitic sandstones, some 20 feet thick, which resemble in appearance the Farewell Rock. The shale band above this (some 6 feet thick and the highest shale band in the succession here) was found to be very fossiliferous. This bed is exposed on the right bank of the stream some 200 yards north of Cwmpedol Uchaf Farm. The following fossils were collected, *Posidoniella* cf. *rugata* Jackson, *Pterinopecten*[1] sp., *Gastrioceras subcrenatum*, and *Gastrioceras* cf. *listeri*. This band occurs at practically, if not identically, the same horizon as that at Craig-derlwyn.

At the top of the Millstone Grit of this area, between typical Farewell Rock and the Astell Vein (the top of the Millstone Grit), there occur some 60 feet of concretionary shales in which some poor fragments of *Carbonicola* sp. were found.

3. *Berach Valley.*

This valley is about a mile west of the Pedol. Shales near the top of the Shale group were found to contain a large number of fragmentary specimens of *Dimorphoceras* sp. These shales are at a lower horizon than the highest shale band found along the Pedol, and seem to be at a very similar horizon to those in which *Dimorphoceras* sp. were found in the Vale of Neath.

The succession as obtained in the Garnant area is therefore seen to include the zones of R_2 (mut. β) and the upper part of G. The horizon of mut. β is found to be at the top of the Basal Grits, and the highest part of the G zone is found in shales at the extreme top of the Shale group or at the base of the Farewell Rock group.

(*c*) *Llandebie* (*Llandybie*) (*Near Garnbica*).

The only fossils collected in this area are from the lower shale bands of the Basal Grits immediately above the Plastic Clay beds. These are exposed in some roadside cuttings near Garn-bica Farm (Ammanford Memoir, pp. 85 and 96) a few miles north-west of Cwmpedol.

These shale bands were found to be fairly fossiliferous; *Orthoceras* and the following pyritized brachiopods were found: *Chonetes* cf. *laguessiana* (de Koninck), *Lingula mytiloides* Sowerby, and *Productus* sp. Some beds are crowded with very small goniatites (none with a diameter over 5·5 mm.). These have a very wide mbilicus, an early serpenticone stage, with smooth shell up to ·5 mm. diameter, after which they are ornamented by regular ndivided striae which cross the venter with neither forward nor ackward projection (the striae averaging 3 per millimeter on the enter). These appear to resemble *Homoceras* cf. *diadema* (Beyrich) rom which they differ in that the striae have no forward projection n the venter.

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[1] See page 169.

These therefore suggest a horizon in H, possibly just below the *triolatum* zone.

d) *Kidwelly* (*Mynydd-y-Gareg*).

Fossils have been collected from shale bands in the Basal Grits xposed in quarries at Mynydd-y-Gareg, about 500 yards south-west f Four Roads. Some adjacent quarries have been shown to be in the D_2 zone of the Carboniferous Limestone (George, 1927, pp. 50 and 51), nd it is therefore calculated that these shale bands are only about 20 feet from the base of the Millstone Grit. Some pyritized fossils ncluding *Chonetes* sp., *Lingula mytiloides* Sowerby, *Orbiculoidea* f. *nitida* (Phillips), and *Posidoniella* sp., have been collected. The hales were also found to contain very large numbers of goniatites, nostly extremely badly preserved impressions, generally showing one of the test ornamentation. Some specimens are identifiable as *Homoceras* cf. *striolatum* (Phillips). Other specimens were also found howing the characteristic hair-like transverse striae which, however, ack the sharp forward curve on the lateral area, typical of *H. triolatum*, and which show an affinity with *H. diadema* (Beyrich) compare Bisat, 1924, p. 50). The base of the Millstone Grit at this ocality therefore is probably at a horizon near the upper part of H or in R_1 (possibly near the *striolatum* zone, and slightly higher than hat at Llandebie) (see Fig. 2).

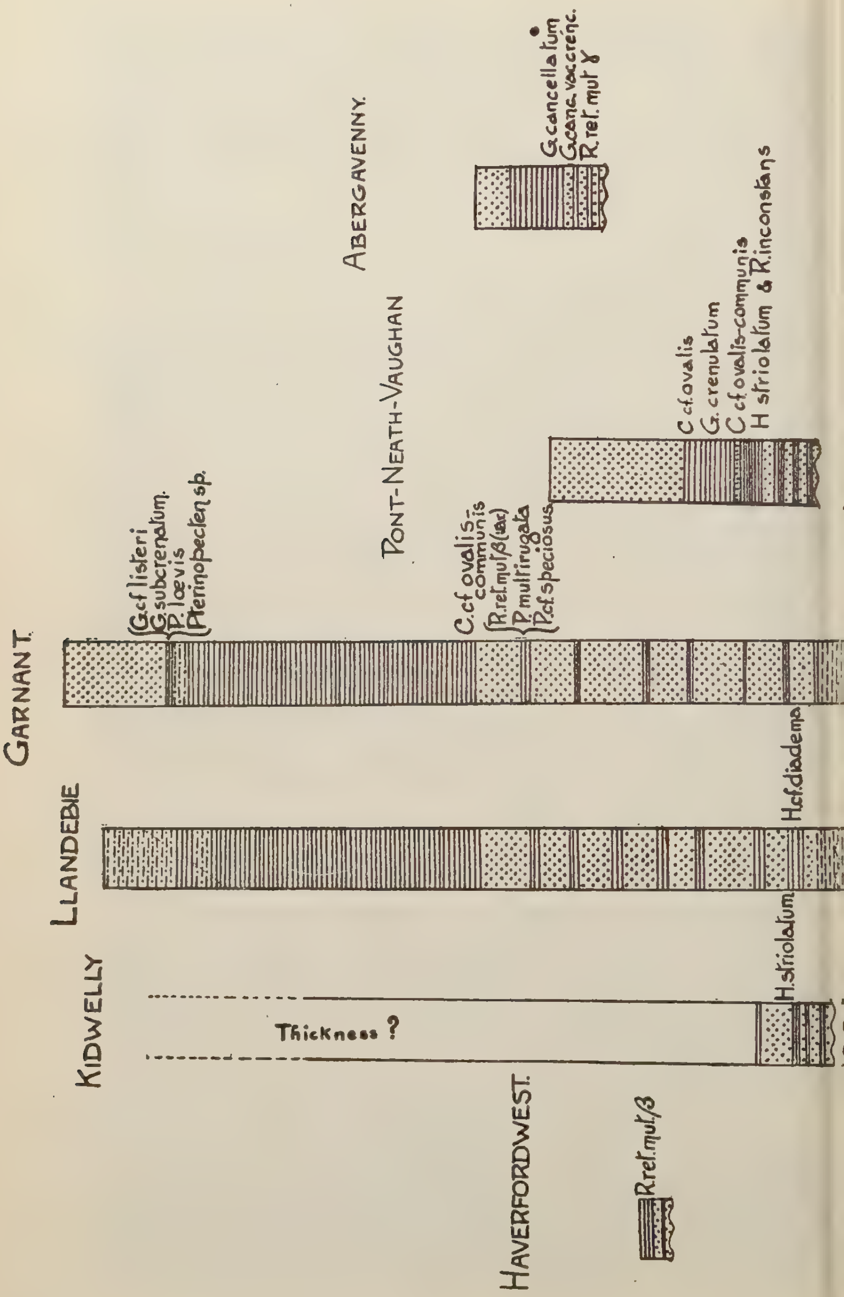
e) *Tenby*.

Although no collecting has been done here by the authors a large umber of specimens from this area have been examined, viz. hose in the Geological Survey Collection (from First Bay), those in he British Museum (Natural History), and two specimens collected y Dr. T. N. George. The following species are represented : *Gastrioceras* cf. *crenulatum* and *G. coronatum* (Foord and Crick), hus proving the presence of the G zone.

III. SUMMARY OF AREAS ALREADY EXAMINED IN SOUTH WALES.

(a) *Pembrokeshire* (*Haroldston St. Issells*).

Professor O. T. Jones showed that there was evidence of an nconformity at the base of the Millstone Grit at Haroldston St. Issels and that a great deal of the latter was missing, when ompared with that further east, owing to overstep (Haverfordwest Memoir, p. 151) ; the total thickness of Millstone Grit in this locality


GARNANT.
LLANDEBIE
KIDWELLY
HAVERFORDWEST.
PONT-NEATH-VAUGHAN
ABERGAVENNY.
G.cf listeri
G.subcrenatum.
P. lævis
Pterinopecten sp.
C.cf ovalis-communis
R.ret.mul.β (var.)
P. multirugata
P.cf. speciosus
C cf. ovalis
G. crenulatum
C cf. ovalis-communis
H striolatum & R. inconstans
G.cancellatum
G.canc. vaccrenc.
R.ret. mul γ
H.cf. diadema
H.striolatum
Thickness ?
R.ret.mul.β

is only about 40 feet. This overstep was lately confirmed by fossil evidence, and it has been shown that *Reticuloceras reticulatum* mut. β occurs abundantly in the shales seen (Jones, 1925, p. 558).

One of the authors has also obtained a large number of *R. reticuloceras* mut. β from the same locality.

(*b*) *Abergavenny* (*Nant Morlais*).

Gastrioceras cancellatum Bisat, *Gastrioceras cancellatum* var. *crencellatum* Bisat and *Reticuloceras reticulatum* mut γ Bisat, have been recorded from shales near the base of the Millstone Grit at Abergavenny (Kitchin, p. 132, also Abergavenny Memoir, 1927, p. 43), thus proving that the lower part of the Millstone Grit here is near the base of the G zone.

IV. GENERAL SEQUENCE OF GONIATITE ZONES.

(*a*) *Base of Millstone Grit.*

It is seen that, wherever information is available along the north crop of the South Wales Coalfield, the zones P (*Goniatites* s.str.), E (*Eumorphoceras*), and practically the whole of H (*Homoceras*), which are found in the north of England (Bisat, 1924) are missing. The lowest zone present varies from area to area, but in no case examined by the writers is a zone lower than Upper H indicated.

It is therefore seen that there is an unconformity present everywhere along the north crop, between the Carboniferous Limestone and the Millstone Grit. This agrees with the conclusions reached by Dr. T. N. George (1927, p. 84), and also by the latter and Dr. T. Robertson (1929) from a study of the Carboniferous Limestone succession in the same area. It is also found that, in general, as the base is traced eastwards from Llandebie the gap is of increasing importance (see Fig. 2).

(*b*) *General Succession.*

So far as the succession affords information, the general goniatite succession determined by Mr. W. S. Bisat in the Millstone Grit of the north of England (1924) seems to hold good for South Wales. Several zones from *striolatum* upwards are traced, but owing perhaps to the generally unfossiliferous nature of the Millstone Grit of South Wales, evidence for some zones has not yet been obtained. The zones of *inconstans* (base of R_1) and of *crenulatum* (G), and also of mut. γ (R_2–G ?) are well seen in the Vale of Neath. The zones of mut β (middle of R_2) and of *subcrenatum* (*listeri*—top of G) are seen in the Garnant area ; while the *striolatum* zone is seen in the Kidwelly area ; and what may be a horizon just lower than *striolatum* is seen near Llandebie. The *mut. γ–cancellatum* zone (R_2–G) has been proved at Abergavenny (Kitchin, 1926) and *mut. β* (middle R_2) at Haverfordwest (O. T. Jones, 1925).

Some brachiopods and lamellibranchs have been found. The former are comparatively rare and appear at present to have no value in correlation. The lamellibranchs also seem of little use, but it is interesting to note that *Posidoniella multirugata* seems to occur at a lower horizon than *Posidoniella rugata* (see J. W. Jackson, 1927). Freshwater lamellibranchs such as *Carbonicola* cf. *communis* and *C.* cf. *ovalis* occur, and are fairly common in some beds, the earliest being found at, roughly, the *mut.* β horizon. This is at a lower horizon than the first recorded appearance in the north of England, which is in G (see Bisat, 1924, p. 52).

V. NOTE ON THE PALAEONTOLOGICAL AND STRATIGRAPHICAL SEQUENCE.

From a study of the goniatite sequence it is found that the mapped divisions of the Millstone Grit (Basal Grits, Shales, and Farewell Rock) are not completely in accord with the palaeontological divisions. It is found that all the Basal Grits in the Vale of Neath are, at most, no younger than the Zone of R_1, while the top of the Basal Grits in the Garnant area is of R_2 age. This is, of course, associated with the apparent expansion in the thickness of the Basal Grits, which are only about 80 feet in the Vale of Neath and 600 feet thick in the Garnant area.

VI. NOTE ON THE RELATION OF MILLSTONE GRIT TO LOWER COAL MEASURES.

Although there is no definite information concerning the relation of Millstone Grit to Lower Coal Measures, it is seen that there is no evidence that any considerable part of the uppermost zones of the Millstone Grit is missing, all the main zones of the upper part of the Millstone Grit of Yorkshire being represented in South Wales.

Further, the fact that *G. subcrenatum* and *G.* cf. *listeri* are found at about 200 feet below the horizon which has been mapped as the top of the Millstone Grit at Garnant, and *G. crenulatum* at a fairly low horizon in the Shales (just above the 12 ft. Grit band) in the Vale of Neath, suggests that part, at least, of the Farewell Rock in certain parts of the north crop may be of Coal Measure age.

From the distribution of the goniatites it is apparent that the main part of the Millstone Grit of South Wales is equivalent in age to the upper part of the Millstone Grit of the north of England. It may be stated definitely that there is no ground for correlating part of the Millstone Grit of South Wales with the Westphalian (Yorkian) or Middle Coal Measures as has been often assumed to be the case on palaeobotonical evidence (see Jukes Brown, p. 305). Mr. J. H. Davies and Dr. A. E. Trueman (1927, p. 253) have suggested that the correlation which has been based on the fossil plants needs to be used with caution and the evidence brought forward in this paper supports their conclusions.

TABLE SHOWING THE GONIATITE ZONES OF THE MILLSTONE GRIT OF SOUTH WALES AND YORKSHIRE.

			Yorkshire (after Bisat, 1924).	*South Wales (North Crop).*
LANCASTRIAN (cf. Lanarkian and Namurian).	G.	(Gastrioceras)	*carbonarium* and *listeri*.	*G. subscrenatum* (at Garnant).
			crenulatum and *cambriense*.	*G. crenulatum* (Vale of Neath).
			cancellatum and Mut γ	*G. cancellatum, G. can. var. crencellatum* and *R. ret.* mut γ (at Abergavenny).
	R.	(Reticuloceras)	R_2 mut γ mut β of *reticulatum*. Mut α	*R. ret.* mut. γ (Vale of Neath). *R. ret.* mut β (at Haverfordwest and Garnant.
			R_1 *reticulatum* (type). *inconstans* (*circumplicatile*).	*R. inconstans* and *H. striolatum* (in the Vale of Neath).
	H.	(Homoceras)	*prereticulatum* (first appearance).	
			striolatum (first appearance).	*H.* cf. *striolatum* (at Kidwelly).
			proteum (first appearance).	
			diadema (first appearance).	*H.* cf. *diadema* (at Llandebie).
	E.	(Eumorphoceras)	*bisulcatum* (first appearance). *pseudobilingue* (first appearance).	
VISÉAN.	P.	(Goniatites s.str.)	*crenistria* (last appearance). *spirale*. *sphaerico-striatus*. *crenistria* (first appearance).	? Absent.
	D_3 and under.		*implicatum, micronotum* (first appearance). *hodderense*. *compressus* (first appearance).	No goniatites as yet recorded.

VII. SUMMARY.

1. There is evidence of an unconformity between Carboniferous Limestone and Millstone Grit along the whole of the north crop of the South Wales Coalfield: the zones P, E, and most of H of the north of England have not been detected.

2. The lowest beds present in the Millstone Grit vary in age from high in H to R_2–G.
3. Many of the goniatite zones of the north of England from *striolatum* upwards have been traced in South Wales.
4. The lithological subdivisions of the Millstone Grit of the area seem in some cases to transgress the zonal divisions.
5. No evidence of any break between Millstone Grit and Coal Measures has been detected.

The authors feel greatly indebted to Mr. W. S. Bisat, F.G.S., for his kindness in checking some of the identifications of their specimens and for his help in naming others.

One of the authors (R. O. J.) wishes to express his thanks to Mr. J. Pringle, F.G.S. and Mr. S. W. Hester of the Geological Survey for loan of specimens and helpful advice and discussions, and to Dr. L. F. Spath, F.G.S., and Mr. A. Reeley, for their help while examining specimens in the British Museum (Natural History).

To Dr. T. N. George, M.Sc., of the University College of Swansea, the writers wish to express their thanks for his most valuable help in the field and laboratory.

This work has been pursued under the guidance of Dr. A. E. Trueman, F.G.S., of the University College of Swansea, whose continued advice and encouragement has made this work possible, and to him they are indebted beyond expression.

REFERENCES TO LITERATURE.

Memoirs of the Geological Survey. "The Geology of the South Wales Coalfield": part i, "The Country around Newport," ed. 2, 1909; part ii, "The Country around Abergavenny," ed. 2, 1927; part v, "The Country around Merthyr Tydfil," 1904; part vii, "The Country around Ammanford," 1907; part xi, "The Country around Haverfordwest," 1914; "The Geology of the Rossendale Anticline," 1927.

Bisat, W. S. 1923. "*Gastrioceras cancellatum* (sp. nov.) at Meanwood, Leeds," *Trans. Leeds Geol. Assoc.*, part xix (1920–3).

—— 1924. "The Carboniferous Goniatites of the North of England and their zones," *Proc. Yorks Geol. Soc.*, vol. xx, pt. i, p. 40.

Jukes-Browne, A. J. *The Student's Handbook of Stratigraphical Geology*, 2nd ed., 1912.

Crookall, R. 1925. "On the Fossil Flora of the Bristol and Somerset Coalfield," Geol. Mag., Vol. LXII, pp. 145 and 385.

Davies, J. H., and Trueman, A. E. 1927. "A Revision of the Non-Marine Lamellibranchs of the Coal Measures, etc.," *Quart. Journ. Geol. Soc.*, vol. lxxxiii, p. 210.

Dixey, F., and Sibly, T. F. 1917. "The Carboniferous Limestone Series on the South-Eastern Margin of the South Wales Coalfield," *Quart. Journ. Geol. Soc.*, vol. lxvii, p. 111.

Dixon, E. E. L. 1921. "The Unconformity between the Millstone Grit and Carboniferous Limestone at Ifton, Mon.," Geol.Mag., Vol. LVIII, p. 157.

—— and Pringle, J. 1927. "The Penlan Quartzite," Summary of Progress for 1926, *Mem. Geol. Surv.*, p. 123.

George, T. N. 1927. "The Carboniferous Limestone (Avonian) Succession of a Portion of the North Crop of the South Wales Coalfield," *Quart. Journ. Geol. Soc.*, vol. lxxxiii, p. 38.

George, T. N. 1928. "The Carboniferous Outlier at Pen-Cerig-calch," Geol. Mag., Vol. LXV, p. 162.

Goode, R. H. 1913. "On the Fossil Flora of the Pembrokeshire Portion of the South Wales Coalfield," *Quart. Journ. Geol. Soc.*, vol. lxix, p. 252.

Hind, Wheelton. 1909. "The Present State of our Knowledge of Carboniferous Geology," *The Naturalist*, 1909, p. 153.

Jackson, J. W. 1927. "New Carboniferous Lamellibranchs and notes on other Forms," *Proc. Manch. Lit. and Phil. Soc.*, vol. lxxi, 1926–7.

Jones, O. T. 1925. "Correspondence," Geol. Mag., Vol. LXII, p. 558.

Kitchin, F. L. 1926. In "Summary of Progress" for 1925, *Geological Survey*, p. 132.

Robertson, T., and George, T. N. 1929. "The Carboniferous Limestone of the North Crop of the South Wales Coalfield," to appear in *Proc. Geol. Assoc.*, vol. xl.

Trueman, A. E. 1924. "The Geology of the Swansea District," *Proc. Geol. Assoc.*, vol. xxxv, p. 283.

Wright, W. B. 1926. "New Goniatites from the Millstone Grit of Lancashire," "Summary of Progress" for 1925, *Geological Survey*, p. 192.

On a Raised Beach on the North Coast of Scotland.

By D. M. Reid, Dept. of Biology, Harrow School.

ALTHOUGH raised beaches are common enough round the British coasts, the presence of such a beach on the north coast of Scotland merits description, were it only to put on record the occurrence of what is, I believe, the first undoubted example of its kind in this locality.

There seem to be some contradictory opinions in existence with regard to the presence or absence of raised beaches on this coast. In their *Textbook of Geology* Lake and Rastall state that raised beaches can be traced on all the British coasts except the north. On the other hand Kendall[1] mentions that raised beaches occur on all the coasts and cites Loch Eireboll on the north. He indicates that there they form the platform on which the terminal moraines have been deposited. With this I fear, I must disagree, since although I have examined the district very closely I can find no clear evidence for the statement. At the head of the loch the boulder-clay rests in general on the quartzites, and their junction, as far as I have been able to ascertain, shows no particular indication that a previous beach has existed there. (Indeed, almost all along that part of the coast the base of the boulder clay is washed by the sea, at least during storms and probably during high spring-tides.)

The area in which occurs the raised beach about to be described forms the southern shore of Balnakiel Bay (Bagh Baille-na-Cille), near Durness, Sutherlandshire (see *Geol. Surv. Scot.*, Sheet 114). This shore is composed of the Durness Dolomites, which form a sea-wall varying from about 30 feet to 50 feet in height. Towards their eastern end they do not form a beach, but pass down vertically into the sea at all states of the tide, while the top of the cliff for most of its length passes evenly into the grassy slopes of the land behind. At one place, however, just less than ¼ mile east of Eilean Dubh, and just over ¾ mile west of Balnakiel Old Church, there is a half-saucer-like depression in the cliff top representing the raised beach which is, therefore, primarily of the " Seter " variety.

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[1] Kendall, P. F., *Handbuch der regionalen Geologie* (iii, i), The British Isles, p. 321.

The floor of this depression, which is some 35 by 40 feet in area, is composed towards the seaward side of much eroded pinnacles of dolomite, while the landward part has a surface composed largely of rubble which may have come down from the slopes above. The line of demarcation between the two parts of the depression coincides with the line of a fault (see Fig. 2), more clearly seen further towards the west.

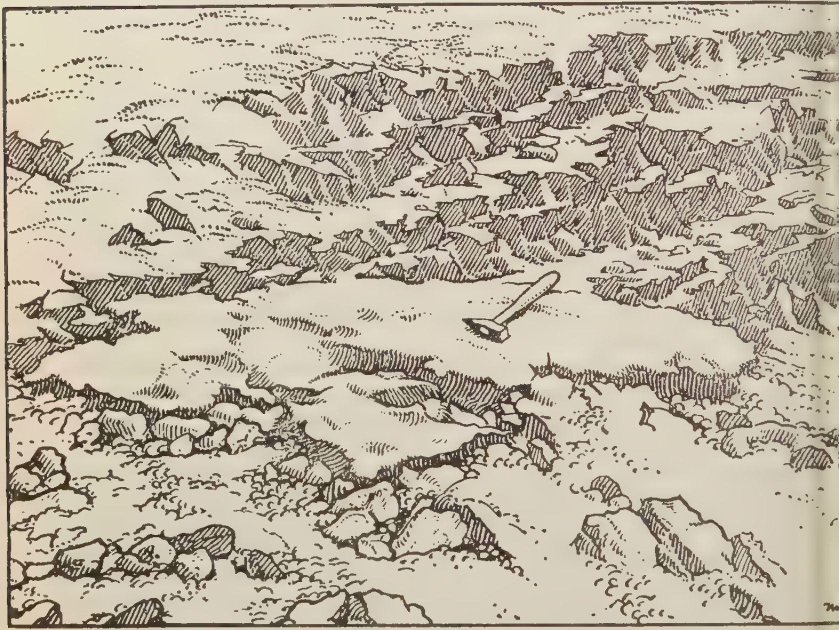

FIG. 1.—Sketch of Remains of Raised Beach, Balnakiel.

In the landward part of the depression is to be found the really conclusive evidence of the old sea beach in the form of " cemented sand ". This sand has suffered greatly from erosion and one fears that in a short time even this small piece of evidence will be completely removed. It is to be seen in isolated pieces which vary in size from about the size of an orange to one large irregular piece roughly 6 feet by 2 feet in area (see Fig. 1). Its maximum thickness is about 10 inches. Despite the amount of erosion to which this cemented sand has been subjected, it has been possible by comparing the larger pieces to divide it into four well-defined zones.

Zone 1 (Lowest zone).—A layer of small rounded to sub-angular fragments of dolomite fixed to the floor of the depression.

Zone 2.—A layer of about 1 inch in thickness of rounded pebbles of dolomite up to the size of a hazel nut.

Zone 3.—A layer of maximum thickness 5 inches, composed of grains of quartz (sand layer).

Zone 4.—A capping of dolomitic pebbles as in Zone 2.

The whole mass is cemented together with calcium carbonate.

MECHANICAL ANALYSIS OF THE SAND.

It was thought advisable to subject the sand of Zone 3 to mechanical analysis so that comparisons with other sands could be made. To this end the calcareous cement of some of the material was dissolved out with hydrochloric acid leaving a clean sand which, on elutriation showed the following grading (where s = silt; F.S., M.S., and C.S. = Fine, medium, and coarse sand respectively):—

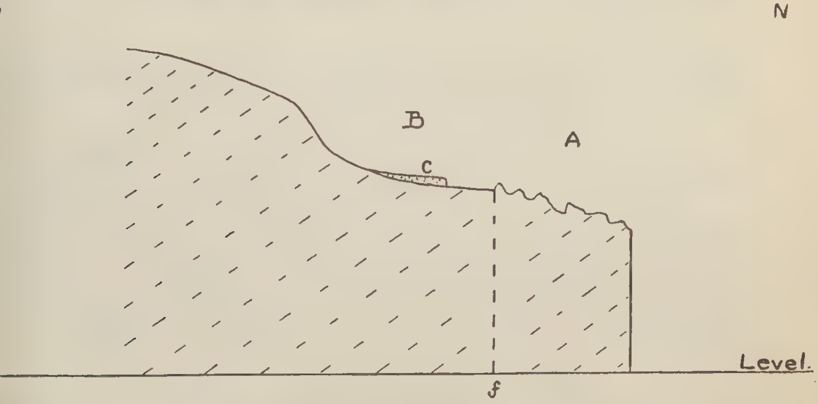

FIG. 2.—Diagrammatic Section of Raised Beach. A. Eroded pinnacles of dolomite. B. Old platform. *c*. Cemented sand (much exaggerated). *f*. Fault.

s	F.S.	M.S.	C.S.
0%	34·9	62·9	2·2%

This seems to correspond in grading to a typical shore sand, as will be seen by comparing the above figures with those for a specimen of sand collected between H. W. M. and L. W. M. in the bay below Beinne Ceannabeinne, some 4½ miles further east.

CEANNABEINNE SAND.

s	F.S.	M.S.	C.S.
0%	41·4	58·0	0·6%

PALAEONTOLOGY.

There is a great lack of variety of animal remains in this mass. All through it there are pieces of molluscan shells, but they are in too fragmental a state to allow of identification. Zone 3 is pierced in many places by burrows which, since they protrude above the surface like small volcano craters but show no definite wall structure, may be considered to be the burrows of some small marine non-tubicolar annelid.

Zone 1 is most curious of all since the fragments composing it may almost be said to be held together by the tubes of a tubicolar worm. Since the latter tubes are themselves composed of very small sand particles cemented together it is reasonable to assume that they are the work of a species of *Sabellaria*.

This beach, standing as it does about 25 feet above sea-level, obviously belongs to the lowest group of raised beaches.

I am indebted to Mr. M. Clarke for the sketch of Fig. 1.

Notes on Graphical Methods of Recording the Dimensions of Ammonites.

By C. H. WADDINGTON, Sedgwick Museum, Cambridge.

THESE notes are concerned with the methods of dealing with data on the dimensions of ammonites, and some general considerations as to the value of such data in ammonite systematics. They are to be regarded as preliminaries to a study which has been made, of Upper Kimmeridge and Lower Portlandian ammonites, in which considerable attention has been paid to the question of dimensions.

METHODS OF ANALYSING THE DATA.

Buckman[1] has laid great stress on the value of the dimensions of ammonites as aids to their identification. He introduced a formula for recording the height and thickness of the whorl-section and the diameter of the umbilicus as percentages of the diameter of the whole shell; and more recently he has made use of a similar formula for recording the lengths of the main lobes of the suture as percentages of the whorl height. His method of expressing the dimensions as percentages of the diameter of the shell has been extensively followed, not always with the happiest results. If it is desired, as it commonly is, to compare the dimensions of one ammonite with those of another, the method of percentages presents several dangers. Consider, for example, the diameter of the umbilicus. If, in a series of shells, this was always a fixed percentage of the diameter of the whole shell throughout the ontogeny of each individual, these percentages could be compared directly with one another, the absolute size of the individuals compared being irrelevant. But in practice it is usually found that the value of the diameter of the umbilicus expressed as a percentage of the diameter of the whole shell is not independent of the size of the whole shell: and for this reason a

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[1] Buckman, S. S., *Yorkshire Type Ammonites*, vol. ii, 1913, p. viii.

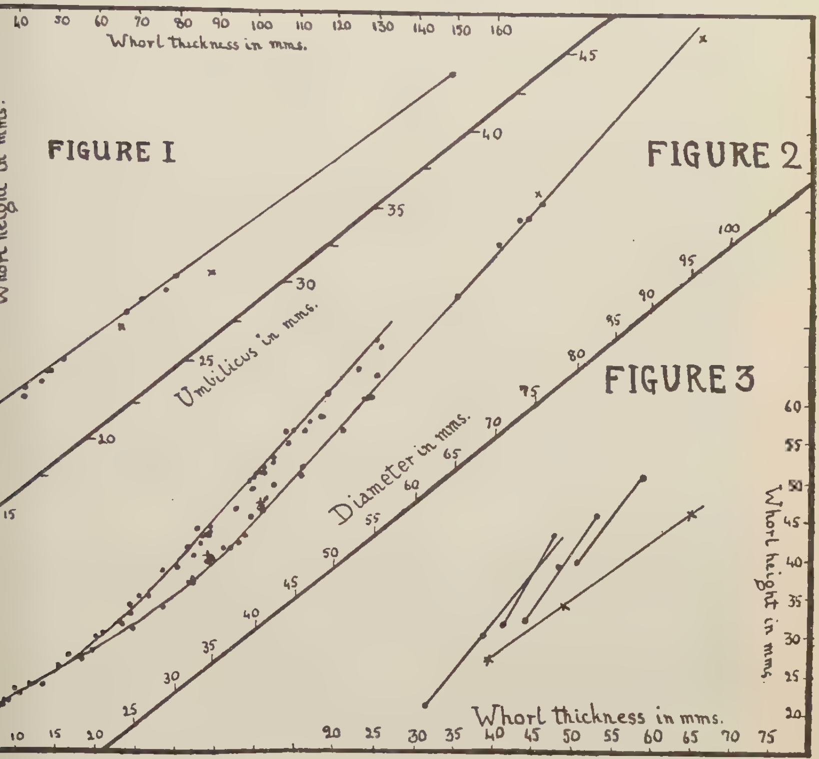

FIG.

1.—The whorl-height plotted against the whorl-thickness for specimens of "*Lydistratites*" *gibbosus* (Buck.). The measurements given by Buckman, *Type Amm.*, vol. vi, pl. DCXXXIX B and vol. vi, pl. DCXXXIX D, are indicated by crosses. They probably differ from my measurements in being taken on top of ribs instead of between them, and are both given as being doubtful.

2.—The umbilicus plotted against the diameter for specimens of *Pallasiceras* (= ? *Pavlovia*) *rotundum* and its allies from Chapman's Pool. Neaverson's measurements for *P. rotundum*, *Amm. Up. Kimm. Clay*, p. 18, are indicated by crosses, and those for *P. gracile*, loc. cit., p. 20, by solid black circles surmounted by crosses ($\overset{+}{\bullet}$).

3.—The whorl-height plotted against the whorl-thickness in some Portlandian ammonites from Swindon. A group of allied forms, indicated by circles, is contrasted with one of its typical associates, indicated by crosses.

comparison of the percentages alone, without taking account of the absolute sizes of the individuals involved, will not be of any value. An actual example may make this clearer. Neaverson[1] has described four species of *Pallasiceras* [= ? *Pavlovia* (Ilovaisky)][2] from the nodule bed of Chapman's Pool in Dorset. Of these species, *P. rotundum* (Sow.) is described as " evolute ", while *P. gracile* Neav. is said to be the most involute of them all. The measurements given by Neaverson are : *P. rotundum*, the umbilicus 48% of the diameter at a diameter of 96 mms. and 48% at 75 mms. : *P. gracile*, 39% at 42 mms. and 36% at 34 mms. From a mere consideration of these percentages, then, Neaverson's conclusions seem reasonable enough. But if the absolute measurements of the diameter and umbilicus are plotted against one another, the points so obtained are found to lie very nearly on one straight line (see Fig. 2), and the difference between the degrees of involution of the two species becomes less obvious. As a matter of fact, if the measurements of a large number of specimens of *P. rotundum* and its allies from Chapman's Pool are plotted, it is clear that the points obtained *do* lie on two straight lines, with Neaverson's *P. rotundum* and *P. gracile* on one line and his *P. pringlei* and *P. concinnum* on the other. There is in fact no justification for saying that the former two species differ from one another in the dimensions of their umbilici ; the differences in the percentages are due entirely to the differences in the actual magnitudes involved.

In such cases as the above, it is, then, of no value to compare the dimensions by first expressing them as percentages, since what is necessary is not, for example, to show that some shell is " more involute " than another, but to show that it is more involute than the other at a comparable size. The only occasion when it is justifiable to compare two percentages directly is when they relate to two measurements of the same absolute magnitude. The method of plotting the actual measurements, which was used in the example given above, is useful because it enables one to see at a glance whether the course of development is the same or different in different ammonites. By taking several measurements on each specimen, one obtains a set of curves which may be either parts of the same curve or distinct from each other. Or by taking one measurement on each of a large number of different specimens, one obtains points which may fall on to a reasonably small number of curves and so divide up the assemblage. This method was strongly recommended by Buckman,[3] but he does not appear always to have used it.

The curves which are obtained by these methods are very frequently straight lines, at any rate over the greater part of their course. Thus in the *P. rotundum*-group, the umbilicus-diameter ines are straight after a diameter of some 30–35 mms. (see Fig. 2). A similar thing is often found when other dimensions are plotted; for instance, in Fig. 1 it is seen that when the whorl-height is plotted against the whorl-thickness in "*Lydistratites*" *gibbosus* (Buck.), the points obtained lie fairly accurately on a straight line from a whorl-thickness of 20 mms. up to the maximum known, 149 mms. When the curves are straight lines, more accurate methods than graphical ones are easily employed. It may for instance, be necessary to show rigorously that a difference in the measurements of two species is really significant and is not due to chance; that is, to show whether there is sufficient evidence to justify the statement that a set of points lies on two straight lines rather than on one. All that it is necessary to do, is to find, for the two groups, the regression coefficients and their probable errors.[1] We may take the *P. rotundum* group as an example of the method employed, which is that given by Fisher.[2] The assemblage is divided into groups 1 and 2, by the aid of the ribbing and the umbilical margin,[3] and we proceed to find the regression coefficients of these two groups. If we put y_1 for the diameter, x_1 for the umbilicus measurements, and $\bar{y}_1$ for the mean diameter and $\bar{x}_1$ for the mean umbilicus n group 1, the calculated diameter Y will be $a + b\,(x_1 - \bar{x}_1)$ where $a = \bar{y}_1$ and $b = \frac{\Sigma\{y_1\,(x_1 - \bar{x}_1)\}}{\Sigma(x_1 - \bar{x}_1)^2}$, a and b being the two regression coefficients: and a similar formula will hold for group 2. In the case we are considering the two lines calculated from this formula are $Y_1 = 43{\cdot}9 + 1{\cdot}79\ (x_1 - 19{\cdot}9)$ for group 1, and $Y_2 = 52{\cdot}6 + 1{\cdot}96\ (x_2 - 21{\cdot}8)$ for group 2. The standard error of a is given by $\sqrt{\frac{\Sigma(y - Y)^2}{n\,(n - 2)}}$ where n is the number of observations, and that of b is $\sqrt{\frac{\Sigma(y - Y)^2}{(n-2)\ \Sigma\,(x - \bar{x})^2}}$. To test the significance of the difference between a and any other value α we calculate $t_{(a-\alpha)} = \frac{(a - \alpha)\sqrt{n(n - 2)}}{\sqrt{\Sigma(y - Y)^2}}$ which is the difference divided by the standard error, and similarly for differences between b and β we calculate $\frac{(b - \beta)\sqrt{(n-2)\,\Sigma(x - \bar{x})^2}}{\sqrt{\Sigma(y - Y)^2}}$. Fisher gives a table showing the probability that, for any number n of observations, any particular value of t will be exceeded by the errors of random sampling. Testing the significance of the difference between the values of a and b in the two lines above, we find that $t_{(a_1 - a_2)} = 9{\cdot}92$ and $t_{(b_1 - b_2)} = 1{\cdot}515$, $n = 27$: the first of these two is overwhelmingly significant, in fact it is outside the range of Fisher's table altogether, while the second would arise as an error of random sampling in between 20 and 30% of cases, and is therefore not significant. We can therefore say that the two lines are distinct; but within the limits of the accuracy of the data they must be regarded as parallel.

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[1] Neaverson, E., *Amm. Up. Kimm. Clay*, Liverpool Univ. Press, 1925, p. 17 et seq.

[2] Ilovaisky, D., *Amm. Jur. Sup. du pays de Liapine*, Ouv. Sect. Géol. Soc. Imp. Amis de Sci. Nat. de Moscou, 1917.

[3] Buckman, S. S., loc. cit., vol. v, 1924, p. 13 et seq.

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[1] This method is only useful when the two groups of shells can be separated by characters other than their dimensions, but it is only under these circumstances that the problem is likely to arise.

[2] Fisher, R. A., *Statistical Methods for Research Workers*, p. 117.

[3] The differences between these two groups will be fully dealt with in a uture publication.

THE VALUE OF MEASUREMENTS IN AMMONITE SYSTEMATICS.

While it is undoubtedly true that a consideration of the dimensions of an ammonite is often a very useful aid to its identification, it must not be understood that it is an Open Sesame to all the secrets of ammonite systematics. In the first place it is not true that no species show any considerable variation in respect of their dimensions. Thus, *P. rotundum*, which has been cited as a species which is very uniform in the dimensions of its umbilicus, is highly variable in respect of its whorl-height and breadth: and it is not possible to separate it into two or three species which are constant in this respect, the group being apparently quite homogeneous. Moreover, the curves which are obtained by plotting the dimensions of a group of conspecific ammonites are not always straight lines, although they usually appear to be during the middle part of their range, any curvature they possess being usually confined to their ends. There is, then, no way of knowing beforehand either whether the dimensions of a new species will, when plotted, fall at all accurately on a single curve, or, if they do, what the form of the curve will be. In these circumstances the sanction for the consideration of the dimensions must be entirely pragmatic. If it is found in any group that the dimensions of a species usually plot as a straight line, it will be to some extent a justification of any new species if it is found to fulfil this condition, while it will not be a matter of great importance if it fails to do so. In this way, a study of the dimensions provides a useful confirmation of the validity of new species. Even if the variation is fairly large, so that the curves obtained for each specimen are not all part of the same curve, the fact that these distinct curves are parallel may express in a convenient way the characters of the group. Thus in the Okus quarry at Swindon there is a group of ammonites of the genus *Kerberites* which have thick depressed inner whorls and elevated outer whorls. If the whorl dimensions are plotted, a series of straight lines are obtained which, although they are not all parts of any one straight line, are parallel and sharply differentiated from the whorl-dimension lines of their associates, being inclined to them at a considerable angle (see Fig. 3). Here the angle of inclination of the lines is a useful way of expressing the peculiarities of the group.

Perhaps the greatest use of data on the dimensions of ammonites is their use in identification. If it is found that a species shows little variation in any of its dimensions, this fact is clearly of the greatest importance for its identification, since the relatively invariable characters in question can be easily and accurately measured, and provide a quantitative basis for comparison with other species. In a group such as the "biplex" ammonites of the Upper Kimmeridgian which exhibits a large degree of homeomorphy, and in which many of the diagnostic characters are therefore subtle and not easy to recognize, the value of such a quantitative basis is very large. And when, as at Chapman's Pool, the ammonites are almost exclusively preserved as fragments, the graphical method is by far the simplest way of comparing different specimens.

While this paper was in the press, I have had the opportunity to see the recent important papers of Brinkman,[1] in which he applies statistical methods to the study of the variation and evolution of the Kosmoceratids, not only in respect of their dimensions but also of the characters of the ribbing, etc. This is clearly not the place to attempt a detailed consideration of the thorough and comprehensive work, but one is perhaps justified in remarking that his methods consist, in many cases, of the comparison of numerical estimates of various characters, expressed as percentages of the diameters of the shell, and are therefore open to the general objections which have been urged against this method; although how far this faulty method invalidates the conclusions in this particular case is a point which it is rather difficult to settle. In most cases his material was rather highly variable, and his problem was considerably more complex than any considered in this paper, which is mainly concerned with material which shows only slight variation.

NOTE ON THE FORMULA FOR THE AMMONITE SPIRAL.

The straight part line obtained when the diameter of the umbilicus of an ammonite is plotted against the diameter of the whole shell, does not, in general, pass through the origin, but is of the form $y = ax + b$, where y is the diameter of the shell and x that of the umbilicus. Blake [2] thought that the formula for the spiral made by the venter of the shell was of the form $r = e^{\beta\theta}$ and that the spiral made by the umbilical shoulders was a retarded portion of the same curve, having a formula such as $r_1 = e^{\beta(\theta - \phi)}$, ϕ being a constant angle. If these ideas were correct, the ratio of the diameter to the umbilicus $\dfrac{e^{\beta(\theta+\pi)}+e^{\beta\theta}}{e^{\beta(\theta-\phi+\pi)}+e^{\beta(\theta-\phi)}}=e^{\beta\phi}=$ a constant, and the diameter-umbilicus line should pass through the origin. It is true in my specimens that the umbilical spiral is a retarded portion of the ventral spiral, at least during that period when the diameter-umbilicus curve is a straight line. If this is so, the formula of the spirals[1] must be $r+c=e^{\beta\theta}$ and $r_1+c=e^{\beta(\theta-\phi)}$.

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[1] Brinkmann, R., "Statistisch-phylogenetische Untersuchungen an Ammoniten," *Zeits. für Ind. Abst. u. Vererbungslehre*, Suppl. Bd. 1, 1928; p. 496; and, by the same author, "Statistisch-Biostratigraphische Untersuchungen an mitteljurassischen Ammoniten über Artbegriff und Stammesentwicklung," *Abh. d. Ges. d. Wiss. zu Göttingen*, N.F., Bd. xiii, 3, 1929.

[2] This is Neumann's "conchospiral". See D'Arcy W. Thompson, *On Growth and Form*, p. 531 et seq., and references given there.

Where $2ac-2c=b$, $e^{\beta\phi}=a$, in which case $y=e^{\beta(\theta+\pi)}+e^{\beta\theta}-2c=a\left[e^{\beta(\theta-\phi+\pi)}+e^{\beta(\theta-\phi)}-2c\right]+2ac-2c=ax+b$, which is what we have seen to be the case. The most remarkable thing about these curves is the peculiar relation between the growth rates of the two edges of the whorl which must be assumed: the ratio between the two rates is not constant, as it is in the equiangular spiral $r=e^{\beta\theta}$ considered by Blake.

SUMMARY.

(1) When the diameter of the umbilicus of an ammonite is plotted against the diameter of the whole shell, or the whorl-thickness plotted against the whorl-height, the curves obtained are very commonly straight lines for the greater part of their courses.

(2) If, as is usually the case, these lines do not pass through the origin, the formula for the ammonite spiral is of the form $r+c=e^{\beta\theta}$ and not $r=e^{\beta\theta}$.

(3) If the straight lines do not pass through the origin, it is useless to express one dimension as a percentage of the other and compare these percentages in different shells.

(4) There is no way of foreseeing, before the measurements are made, whether the dimensions of a species will plot accurately on a single curve or whether they will show a considerable amount of scatter. If, however, they do fall accurately on a single curve, this fact is an argument for the validity of the species, and the curve is a useful aid in the identification of other specimens.

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[1] See note 2, p. 185.

REVIEWS.

Der Bau der Erde. By L. Kober. 2nd ed., pp. 499, with 2 plates and 138 text-figures. Berlin: Borntraeger, 1928.

IN this book the author's first concern is with the structure of the earth's crust as revealed by geology; his second is with the history of its development, also a geological question; his third is with the causes that led to that development, a problem of geophysics rather than of geology proper. Thus he follows the logical course of presenting the facts first and discussing theory afterwards, but with one unavoidable qualification. In complicated areas and in regions that are little known our idea of the structure is an interpretation of facts rather than the facts themselves, and differences of opinion are possible. But Kober is not dogmatic and so far as space permits he discusses doubtful points. Above all, he does not select his facts to fit a preconceived theory. For this reason, as well as others, his work forms the most powerful text-book of the subject that is now available.

The first edition was published in 1921, and was reviewed in the Geological Magazine in the same year (p. 378). The new edition has been almost entirely rewritten and greatly enlarged. The 324 pages of the earlier edition have become 499, and instead of 46 figures in the text, there are now 138; but the mode of approach remains the same and there is the same clearness and simplicity of style.

The leading idea throughout the work is the essential difference between the "Kratogen" and the "Orogen", which may be roughly defined as the rigid and the flexible areas of the earth's crust. In the new edition the contrast is still more strongly emphasized than it was in the first. The chapter on the material of the crust has now separate sections on the kratogenic and the orogenic rock-series. Earth-movements in the kratogen are described apart from those in the orogen. Mountain-building is now recognized in the kratogen as well as in the orogen, but it is of a different type. The former is illustrated by a description of Saxonian tectonics as interpreted by Stille, the latter by reference to the Alps and connected ranges.

After the introductory chapters dealing with these general matters, the author proceeds to a detailed analysis of the structure of Europe and a shorter account of the remaining continents. Then follows a discussion, admittedly speculative, of the structure of the ocean basins. Amongst the illustrations in this section is a bathymetrical map of the South Atlantic based on the echo-soundings of the *Meteor*, which seems quite inconsistent with the idea that the Atlantic floor is formed of sima. A chapter with the same title as the book itself is not a summary as might perhaps be expected.

It deals rather vaguely with certain general notions and then discusses the distribution of gravity anomalies.

The last two chapters are definitely devoted to theory. The first of them, dealing with continents and oceans, discusses the theories of permanence, of continental bridges, of continental drift, of geosynclines, and Kober's own orogen theory. The second is concerned with the many diverse theories of earth-movements and mountain-building, and the less numerous notions about the plan of the earth, such as Lowthian Green's tetrahedral theory and its later modifications. Kober attributes the first conception of the tetrahedral idea to Owen in 1857, but it was also broached by Lowthian Green in the same year, in a paper published in the *Edinburgh New Philosophical Journal*, although it was not till 1875 that his book upon the subject appeared. Kober himself, while not accepting such theories in their entirety, thinks that there is much more regularity in the plan of the earth than is generally conceded.

The two folding maps which summarize Kober's ideas of the structure of Europe and of the earth are rather roughly drawn for so complex a design. It is easy enough to proceed from the explanation to the map but not very easy to go from the map to the explanation. There is no index, but a full table of contents makes some amends for its absence. The bibliography is fairly extensive, but is not very closely related to the text. In the latter, original papers are usually alluded to by the name of the writer only, without further reference, and many of the names do not appear in the bibliography. Occasionally, on the other hand—the names of Ampferer and Joly may be cited as examples—there is a reference in the bibliography and but little more in the text. These are the chief deficiencies in a very useful book.

P. L.

THE PLANT-LIFE OF THE BALKAN PENINSULA: A Phytogeographical Study. By W. B. TURRILL. (Oxford Memoirs on Plant Geography.) pp. xxii + 490, with plates, maps and figures (not numbered). Oxford University Press, 1929. Price 30*s*.

STRICTLY speaking only one short section of this fine book is of direct concern to the geologist, namely chapter ii, which contains a very useful summary of the geology of the Balkan Peninsula, evidently founded on extensive reading in this rather inaccessible subject; but it is pleasant to note that throughout the work much attention is paid to the influence of geological factors, tectonics, and marine transgressions in the earlier periods and glaciation at later stages, on the present distribution and affinities of the Balkan flora. From his own point of view the writer is justified in stating that it is only the events since the appearance of the Angiosperms that directly concern him; therefore his sketch of pre-Cretaceous geology is slight, but still useful. Much stress is laid on the dominance and persistence in this region of the ancient Rodope massif and its influence on all later tectonics, and especially on the trend-lines of the Tertiary fold-chains. There is also a very useful correlation of the Mediterranean stages of Suess with the more usual stratigraphical nomenclature. Much attention is naturally paid to the soil-types characteristic of each geological formation there represented, and the special conditions that have determined them, and the work will also be of value to soil-students.

THE CARBONIFEROUS GONIATITE ZONES OF ENGLAND AND THEIR CONTINENTAL EQUIVALENTS. By W. S. BISAT, Congrès de Stratigraphie Carbonifère, Heerlen, 1927, pp. 117–33, with 2 plates. Liége : Vaillant-Carmanne, 1928.

IT is not intended here to do more than to draw the attention of workers on the Carboniferous to this extremely valuable publication, which gives a clear summary of the goniatite-bearing strata of the Midland Province of England, together with a folding table showing the correlation with the strata of the same facies in Westphalia, Belgium and Holland, and so far as known, in Portugal. It is said that at least fifty goniatite-zones are known, and the number is continually being increased.

THE GEOLOGY OF THE COUNTRY AROUND THE LONELY MINE, BUBI DISTRICT. By A. M. MACGREGOR. Southern Rhodesia Geological Survey Bulletin No. 11. Salisbury, 1928.

THIS well-printed and well-illustrated memoir, with 3 maps, one coloured, describes the geology of about 760 sq.m. of the northern part of the Bembesi gold-belt, with special reference to the Lonely mine, which is now the deepest on a quartz reef in Africa, and has yielded gold worth £3,655,000. The formations present are the Rhodesian Basement Schists, of early Precambrian date, a small part of the Upper Karroo System, and the probably Tertiary Kalahari Beds. The lowest division is in two parts, separated by an unconformity, the Greenstone Series below, mainly volcanic, and the sedimentary Ndutjana Series above. There are also many intrusive igneous rocks, from serpentine to granite. The prevailing strikes range from north-south to north-east–south-west.

The ore-body is a great quartz-reef, striking nearly due north and dipping west at an angle gradually flattening out in depth, from 82 degrees to 60 degrees. According to pl. vii, the workings lie in a great shoot, pitching south at some 45 degrees. The ore contains only pyrite in the upper levels, zinc-blende, galena, and chalcopyrite coming in successively below. A very remarkable feature is the oxidation of the ore to a depth of over 3,000 feet. This oxidation may have occurred as a result of earth-movement along the vein at a time when surface conditions were specially arid, thus greatly lowering the water-table, but so great a depth must be almost unprecedented, even in the driest parts of Western America, whether north or south.

A CONTRIBUTION TO THE GEOLOGY OF THE PUNJAB SALT RANGE.

By C. S. Fox. Rec. Geol. Surv. India, vol. lxi, part ii, 1928.

THE author of this interesting memoir remarks, with truth, that the geology of the Salt Range has given rise to a great deal of controversy. When reduced to its elements this controversy really amounts to a discussion of whether the salt-beds are of Cambrian (or even Precambrian) age, or Tertiary. To the ordinary academic geologist this would appear to be a problem easy of solution, but recent work on salt-bearing strata, especially in north-western Germany and the Middle East has shown that such can do very extraordinary things, and that when they come into the problem the canons of text-book geology have to be abandoned. Owing to its solubility in ground-water such a truly sedimentary deposit can flow readily and behave in many ways like an intrusive igneous magma, even bringing up to the surface for our inspection xenoliths of deep-seated rocks.

Dr. Fox brings forward strong arguments to show that the salt beds form the lowest part of the Cambrian succession, having been originally followed conformably by the Purple Sandstone and the Neobolus beds ; their present peculiar relations in many places can be explained to a very large extent by plastic deformation and flow, with perhaps land-slipping on a large scale. A comparison is made between these rocks and the Hormuz series of Persia, as described by Dr. Pilgrim.

REPORTS AND PROCEEDINGS.

GEOLOGISTS' ASSOCIATION.

1*st March*, 1929.

S. E. Hollingworth, M.A., B.Sc., F.G.S. : " The Evolution of the Eden Drainage in the South and West."

The present river system of the Eden is considered to have originated as a series of consequent streams flowing down the north-eastern and northern slopes of a curved anticlinal region of uplift concave to the north-east. The upper portions of the valleys of the Caldew and of the numerous streams from the north-easterly slope of the Lake District, together with Wasdale Beck and the drainage of the northern slopes of the Howgill Fells, are the direct descendants of such a series. Modifications of the drainage—mainly by the development of subsequent streams along the base of the Carboniferous—have been so extensive that only two of these streams, the Eamont and the Eden itself, retain their original ourses. Gaps in the Carboniferous escarpment indicate the deserted alleys of many of these streams.

The relation of the headwaters of the Eden drainage to those of he Derwent, Ure and Lune are discussed, particular attention being given to the extraordinary sequence of events by which the northerly drainage of the Howgill Fells and some of the north-easterly drainage of the Lake District was diverted to a southward course through he Howgill Fell—Lake District axis.

M. Chatterjee : "The Accessory Minerals in the Bodmin Moor Granite."

The paper describes the typical assemblage of accessory minerals haracteristic of the Bodmin Moor granite mass, as a whole. The features of this assemblage, though in general agreement with those of other West of England granites (particularly the Dartmoor and Falmouth masses), prove to be distinctive in detail. The comparative results for the three granite masses dealt with are offered n the hope that they may be found applicable to provenance problems raised by sediments in the South and South-West of England.

OBITUARY

Thomas Owen Bosworth, M.A. (Camb.), D.Sc. (Lond.), F.G.S.

Born 28th March, 1882. Died 18th January, 1929.

T. O. Bosworth was born at Spratton, Northamptonshire, and became a Scholar of St. John's College, Cambridge, in 1902. He was placed in the first class of the Natural Sciences Tripos (Part 1, 1905 ; Part 2, 1907) and was awarded the Harkness Scholarship. From 1904 to 1911 Bosworth devoted his spare time to the study of the Keuper Marls of Leicestershire and the results of his investigations were published in *The Keuper Marls around Charnwood* (Leicester, 1912), in which after describing the physical character, stratigraphy and petrology of the marls he discusses their mode of origin. In the years 1908 and 1909 Bosworth was on the staff of the Geological Survey of Scotland and mapped part of Mull under the direction of C. T. Clough. After leaving the Survey the greater part of his life was spent abroad as an oilfield geologist, working in Galicia, Italy, Trinidad, Barbados, Peru, Venezuela, Ecuador, Texas, the United States and Canada to within the Arctic circle. Although his professional work was economic his primary interest was in pure geology, but owing to want of time and other restrictions much that he did remains unrecorded. He will, however, be long remembered by his great work on the *Geology of the Tertiary and Quaternary Periods in the North-west Part of Peru* (London, 1922). Scarcely anything was previously known of the geology of this region and the investigations, extending over several years, were carried out under the trying conditions of a desert climate and a rugged country. Of this work one reviewer wrote: "The story revealed is of enthralling interest, most clearly presented by Dr. Bosworth, but worthy of the pen of a Lyell, a Suess, or a Geikie." His other publications include *Geology of the Mid Continent Oilfields—Kansas, Oklahoma and North Texas* (New York, 1920) and several papers in the GEOLOGICAL MAGAZINE: "Wind Erosion on the Coast of Mull" (1910), "Outlines of Oilfield Geology" (1912), "Heavy Mineral Grains in the Scottish Carboniferous" (1912), "Semi-Arid Conditions in Southern Texas" (1913). He was awarded the Wollaston Fund in 1921.

For several years Bosworth had suffered from ill health, but with characteristic pertinacity he stuck to his work until it was no longer possible. As recently as last August he left England for Ecuador, intending to stay a year, but by November he became seriously ill and was compelled to return. He arrived in London in January and died a week later.

CORRESPONDENCE.

THE MOON AND RADIOACTIVITY.

Mr. V. S. Forbes' contribution to the February number of the GEOLOGICAL MAGAZINE on the "Moon and Radioactivity" is very timely.

The naked surface of our satellite, being free from either denudation or sedimentation, provides a good medium on which some of the modern terrestrial geological theories may be tested.

The igneous histories of the two spheres should be somewhat similar and as geological cycles are now recognized for the earth, they may be expected on the moon.

It is important to ascertain whether these events are in phase in both globes, for if such be the case an exterior force may be expected to be in control, while if out of phase, processes within each sphere should be in command. Joly's radioactivity theory, which should apply to the moon as well as the earth, relies on a process acting within the sphere itself. Owing to differences of both mass and composition, the periods of fusion by radioactive heat cannot be expected to coincide in the two spheres.

Mr. Forbes produces considerable data to show that the moon, like the earth, has geologically recently passed through an igneous revolution.

The evidence available to date favours the idea that the geological cycles in the two spheres are in phase. To produce the simultaneous migration of magmas in both the earth and its satellite, an exterior or tidal force may be looked for.

LESLIE H. OWER.

20 AYNHOE ROAD,
WEST KENSINGTON, W. 14.
24th February, 1929.